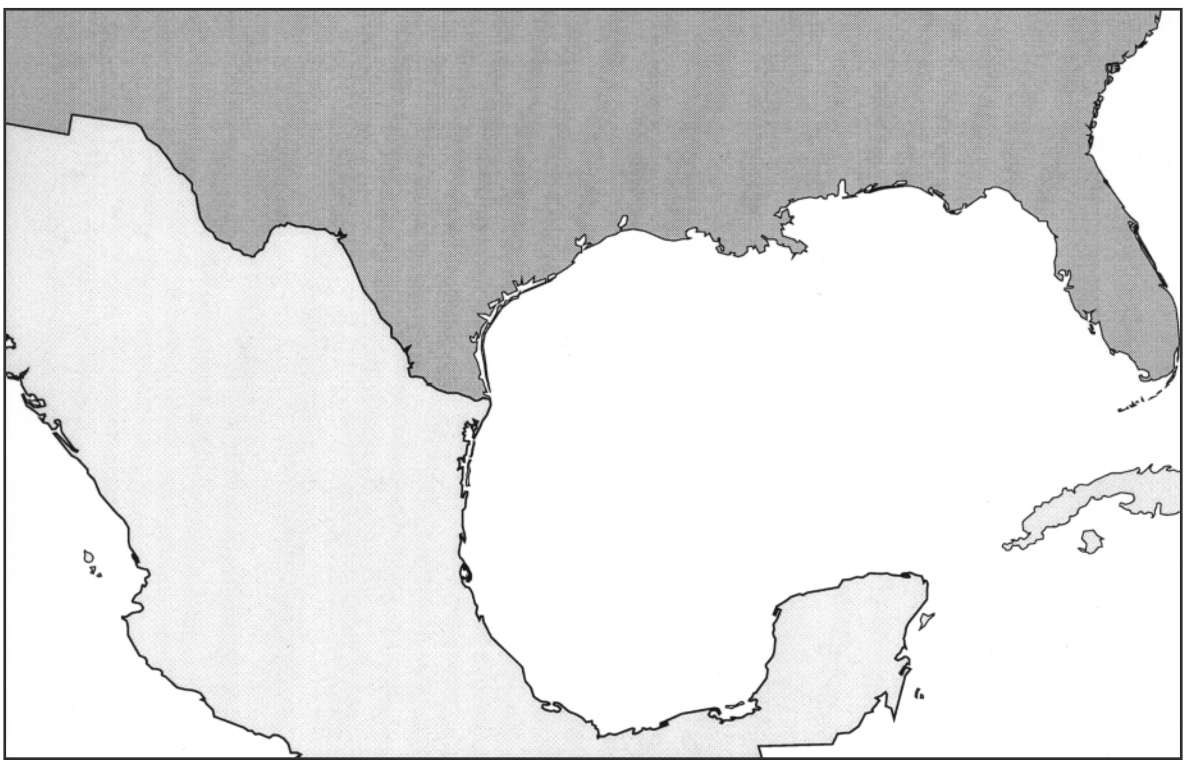
Critical Scientific Research Needs Assessment for the Gulf of Mexico Program

Prepared by:
Research Subcommittee of the Monitoring, Modeling and Research Committee
for the Gulf of Mexico Program Office



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CONTENTS

NOTICE

This document was prepared by the Research Subcommittee of the Gulf of Mexico Program's Monitoring, Modeling, and Research Committee (MMRC) with the assistance of numerous technical experts, primarily from universities in the Gulf of Mexico Region of the U.S. and from federal agencies with responsibility for the Gulf of Mexico. The MMRC is a subcommittee of the Gulf of Mexico Policy Review Board, a chartered Federal Advisory Committee to the Administrator of the U.S. Environmental Protection Agency. This document has been reviewed by the members of the MMRC and the Focus Teams of the Gulf of Mexico Program. While there will always be controversy concerning opinions regarding priority research needs, the reader is reminded that teams of practicing, technical experts, with detailed knowledge of the subject matter, provided the recommendations contained herein.

The primary goal of this document is to identify critical research needs in areas of interest to the Gulf of Mexico Program. Its sole purpose is to provide information to assist federal, state, and private funding organizations, particularly partners of the Gulf of Mexico Program, to develop research plans that support scientific needs of the Program. It is not intended as a stand-alone document to be used by a single agency as a research or budget document.

DISCLAIMER: *This report and recommendations have been written as a part of the activities of the Gulf of Mexico Program Policy Review Board, a federal advisory committee providing external policy information and advice to the Administrator and other officials of the U. S. Environmental Protection Agency (EPA). The Board is structured to provide balanced, expert assessment of issues related to the water quality and living resources of the Gulf of Mexico ecosystem.*

This report has not been review for approval by the EPA and, hence, its contents and recommendations do not necessarily represent the views and policies of the EPA, nor of other agencies in the Executive Branch of the federal government, nor does mention of trade names or commercial products constitute a recommendation for use.

ABSTRACT

This Critical Research Needs Assessment describes the approach used by the Gulf of Mexico Program to define the major environmental issues/problems of the Gulf of Mexico and to determine the major scientific uncertainties that prevent a complete and reliable definition of the problems and their causes. Research to solve these uncertainties, and the scientific products (reports, methods, data, models) needed to support environmental decisions in nine important issue areas are described.

Executive Summary

The Gulf of Mexico is an ecologically, economically rich ecosystem that is increasingly impacted by physical, chemical, and biological stresses directly related to human activity. The health and environmental problems, and their causes, in the Gulf are numerous, complex, and often interconnected and the financial and technical resources required to understand and solve them are limited. In response, the Gulf of Mexico Program (GMP) is working to facilitate the protection and restoration of its coastal habitats, sustain living resources, protect human health and the food supply, and ensure the recreational use of Gulf shores, beaches and waters in ways that are consistent with the economic well-being of the region.

In an effort to understand and solve the most important health/environmental problems in the Gulf Coastal Zone, the GMP has formed four Focus Teams to address those problems: Nutrient Enrichment, Habitat, Public Health and Invasive Species. In addition, the GMP organized the Monitoring, Modeling and Research Committee (MMRC) as an operational committee to provide advice, identify requirements, and coordinate monitoring, modeling, and research efforts in the GMP. In coordination with the MMRC, nine panels of scientific experts from Gulf State and Federal agencies have identified critical scientific research that is needed to understand and address environmental and public health issues facing the Gulf of Mexico Ecosystem.

The nine panels of experts provided the scientific expertise to create the *Critical Scientific Research Needs Assessment for the Gulf of Mexico Program*. This document describes critical research needs required to understand major health and environmental issues in the Gulf of Mexico Region and to lay the foundation for future initiatives to address those needs. Issues and objectives identified by the nine panels include:

I. Nutrient Enrichment - Estuarine Hypoxia

A. Determine the importance of anthropogenic versus "natural" processes in the formation of hypoxia/anoxia in Gulf estuaries.
   1. What evidence suggests that hypoxia occurs naturally in Gulf estuaries?
   2. Determine the roles physical processes have in the onset of hypoxia.
   3. Determine which nutrients, or combinations, are most strongly linked as contributing factors to anoxia.
   4. Determine how anthropogenic sources vs. natural sources of dissolved organic matter affect the magnitude and species composition of algal production.
   5. Determine the relative roles of external vs. internal, re-cycling nutrient supplies in maintaining primary production.

B. Develop an index that will improve the assessment of "estuarine susceptibility" to nutrient enrichment for Gulf of Mexico estuaries.
   1. What are the most useful classification systems and their levels of predictability?
   2. Are there biochemical early warning indicators of impending hypoxia formation?
   3. Determine what environmental conditions are useful in predicting the intensity, frequency, duration, and physical extent of hypoxia.

C. Determine how the frequency, duration and intensity of hypoxia/anoxia events affect estuarine biological communities.
   1. What migratory species are at greatest risk to life cycle completion due to hypoxia events?
   2. Are macro-fauna community biomass and structure indicative of conditions favoring hypoxia?

3. Determine if there is a relationship between occurrence of hypoxia and changes in the food web between benthic organisms and planktonic grazers.

D. If estuarine hypoxia is a problem in the Gulf of Mexico, determine what management practices would have the greatest effect in minimizing these conditions.

1. What are the relative effects of nutrient loading, nutrient ratios, bathymetric modification, regulation of freshwater input, etc., on hypoxia/anoxia in Gulf estuaries?

E. Develop a quantitative assessment of estuarine hypoxia/anoxia for Gulf estuaries.

1. Define the critical information/data required to assess the extent of hypoxia in Gulf estuaries.
2. Define the major uncertainties associated with available data to characterize the frequency, duration, extent, and intensity of hypoxia in Gulf estuaries.

II. Nutrient Enrichment - Coastal Hypoxia

A. Determine the past, current, and potential impacts of hypoxia on commercially and economically important species and ecosystem.

1. Conduct a retrospective analysis based on sediment cores and existing data bases.
2. Effects of other factors that affect the ecological health and fisheries of the Northern Gulf of Mexico.

B. Define the dynamics and timing of transport of N (nitrogen) and other nutrients from the landscape into streams and coastal waters.

C. Develop innovative demonstration projects, watershed partnerships, and adaptive management practices.

1. Define geographic location and design criteria for wetlands and other strategies for effective nitrate reduction.
2. Determine the influence of on-farm practices on transport of N and other nutrients into streams.
3. Develop better methods to intercept agriculture nutrients between the fields and ground water and adjacent streams.
4. Describe the effectiveness of current and potential policies and actions to reduce nutrient loss on a basin scale.

III. Nutrient Enrichment - Harmful Algal Blooms (HABS)

A. Develop a catalog of investigators/facilities that are capable of and willing to provide analyses of Gulf of Mexico HAB samples, as well as provide assistance to event response efforts.

B. Develop and enhance satellite and aircraft remote sensing capabilities to monitor and track blooms at local and regional scales.

C. Develop economic impact figures for *Gymnodinium breve* red tides.

D. Assess cyanotoxin accumulation in higher trophic level species and threats to human and animal health and determine the roles of nutrient enrichment and managed freshwater flow in bloom development.

E. Develop guidelines for siting mariculture facilities in coastal waters that incorporate hydrographic conditions, water quality data, rearing practices, and historical HAB events.

F. Identify HAB species in ballast sediment in ships from Gulf of Mexico ports.

IV. Atmospheric Deposition

A. Quantify atmospheric N deposition (oxidized, reduced, and dissolved organic N) to the Mississippi-Atchafalaya River Basin, estuaries and their watersheds, and the waters of the Gulf of Mexico.

1. Identify and fill data gaps in ambient monitoring for wet and dry N deposition.
    a. Assess the applicability of available data to assess contribution of atmospherically deposited N. Identify data gaps.
    b. Evaluate the feasibility of expanding wet deposition measurements to include organic N or a surrogate.
    c. Collect basic monitoring data within the Gulf coastal land area for wet deposition of N using National Atmospheric Deposition Program/National Trends Network (NADP/NTN) protocols.
    d. Increase dry deposition measurements in the Mississippi Basin to supplement NADP/NTN and Clean Air Status and Trends Network (CASTNet) programs.
2. Collect atmospheric chemistry and meteorological data to validate locally the dry deposition inferential model and to calibrate a synoptic-scale transport model.
    a. Improve methods of estimating dry deposition of nutrient gasses and aerosols directly over water surfaces.
    b. Review the availability of weather data to satisfy the level of modeling precision desired for coastal processes.
    c. Access the adequacy of sampling rate and frequency of wet and dry deposition observations.

B. Assess the role that increases in human and domestic animal population densities in the Mississippi River Basin and states that border the Gulf of Mexico may have on direct and indirect atmospheric N. deposition to the Gulf of Mexico and its estuaries.

1. Quantify the range of effect of nutrient deposition from urban, agricultural and industrialized regions.
    a. Investigate the availability of emissions inventories.
    b. Improve the emission inventory for ammonia.
    c. Examine the urban plume influence on total nutrient deposition, particularly direct deposition, to Gulf waters through intensive, event-based wet deposition studies coupled with dry deposition measurements.

C. Investigate the significance of the land-sea-air interface in estimating total deposition amounts.

1. Quantify the interactions of reactive N species with sea salt and the recirculation effect of the land/sea breeze and the warm Gulf of Mexico waters.
    a. Quantify the influence of sea salt aerosols on dry deposition estimates through co-located measurements of particulate size distribution/chemical composition and trace gas concentrations of oxidized N compounds.
    b. Investigate the role of land and sea breezes on nutrient wet and dry deposition along the Gulf Coast and over near-shore water.

V. Habitat - Emergent Coastal Wetlands

A. Evaluate the success of coastal emergent wetland restoration approaches, emphasizing re-constructing ecological functions.

1. Conduct long-term studies to determine the success of emergent wetland restoration with respect to ecological values.

2. Assess the effects of large scale freshwater diversions on emergent wetlands and adjacent sub-tidal systems and fishery species.
3. Determine the potential for Gulf-wide, standardized, rapid assessment protocols of wetland function, loss, and restoration success.

B. Evaluate innovative means for performing successful restoration.

1. Develop innovative and/or low-cost techniques of restoration and assessments of optimal configuration.

C. Determine the status, structure, and function of coastal wetland systems and develop tools to evaluate these systems over large spatial and temporal scales.

1. Conduct spatial scale studies of the relationships among wetland systems linked hydrologically and by common faunal use.
2. Develop and apply remote sensing and GIS tools for assessing long-term change in emergent wetlands.
3. Conduct population and community dynamics studies to determine how these systems function and change over time and to document ecological factors underlying long-term changes.

D. Determine habitat linkages of coastal wetland and attendant estuarine systems.

1. Quantify the linkages among emergent wetlands, submerged systems, and fisheries.

E. Determine effects of disturbance (human and natural) on productivity and longevity of coastal wetland systems.

1. Conduct studies of plant-herbivore/parasite/disease/contaminant disturbance relationships and effects on productivity, reproduction/colonization, wetland loss, and habitat value of emergent wetland type.

F. Determine the effects and interactions among biogeochemical factors and environmental stressors on emergent wetland systems and habitat utilization.

1. Analyze the effects of biogeochemical factors and soil features on wetland species and on species-species interactions.

VI. Habitat - Seagrasses

A. Assess the ecological status (areal and temporal extent) and condition of seagrasses in the Gulf of Mexico and change over time.

1. Quantify and map current seagrass acreage.
2. Identify indicators that best describe quality of seagrass beds and are appropriate for long-term monitoring and assessment.
3. Define the monitoring and assessment protocols and sampling designs to routinely monitor seagrass beds.

B. Identify factors which determine establishment and persistence of seagrasses.

1. Quantify and map geological and historical seagrass acreage to determine quantity and locations of declines.
2. Determine cause-effect relationships and describe stress thresholds for effects.
3. Correlate seagrass condition with sources to determine cause-effect hypotheses.
4. Document major destruction caused by biological stressors and determine cause(s), including eractions with anthropogenic stressors.
5. Define water column and sediment characteristics required for establishment of seagrasses in areas to be restored.

6. Document and monitor restoration success rates of existing and new seagrass planting technologies.

C. Determine the critical factors which determine natural structural and functional characteristics of seagrass habitats.

1. Determine if and how habitat function (e.g., fish and shellfish utilization) differs in and among different species and densities of Submerged Aquatic Vegetation (SAV).
2. Determine the relationships among primary and secondary productivity and landscape features.

VII. Human Health - Pathogens

A. Pathogen Indicators

1. Are the current indicator recommendations adequate or are new indicators better at predicting disease outcomes in human beings?
2. Is there a single indicator which could be used for both recreational and shellfish purposes that would adequately protect the public?
3. Is there a method available to rapidly detect the indicator of interest?
4. Is there a difference in the risk of disease related to exposure from human vs. non-human sources of indicator organisms?

B. Pathogenic Organisms

1. What organisms may be present at levels that would cause disease endpoint in humans when indicator levels are acceptable?
2. Is there a method available to rapidly detect the organism of interest?

C. Pathogen Source Tracking

1. What are the best methodologies to use to conduct source tracing?
2. Of the methodologies identified above, what is the minimum dataset necessary to construct a valid library of sources?
3. To what geographic extent can a bacterial library be applied?

VIII. Human Health - Toxic Substances

A. Characterization of Mercury and other toxic compound levels in aquatic species

IX. Invasive Species

A. Risk Analysis

1. What methods, data, and models are required to assess the risk of trade pathways and trade partner sources associated with invasive species introductions?

B. Prevention of new introductions

1. Determine preventive strategies and develop model control mechanisms.
2. Develop risk assessments for potential and initial presence of invasive aquatic species.
3. Inventory Gulf marine waters for invasive species.

C. Reducing the spread of established invasive species populations

1. Develop basin-specific and Gulf-wide databases to pinpoint and track invasions and spread of invasive aquatic species.
2. Conduct a status and trends analysis of aquatic and terrestrial invasive species.
3. Develop monitoring protocols for incorporation into existing water quality monitoring to identify presence of invasive species.
4. Inventory Gulf marine waters for invasive species.

D. Ballast water - management and treatment

1. What methods, data, and models are required to assess the risk of ballast water pathways and trade partner sources associated with invasive species introductions?
2. Develop mechanisms to ensure that open ocean exchanges have been performed.
3. Develop mechanisms to regulate ballast water discharge.
4. Refine methods/procedures for monitoring compliance of ballast exchange in the Gulf.
5. Characterize biological contents of ballast discharges in major ports.
6. Establish a long-term database of shipping activities in Gulf ports.
7. Determine the effectiveness of ballast water exchange in killing or removing organisms in ballast water and sediments.
8. Determine the effectiveness of ballast water exchange in preventing the establishment of reproducing, self-sustaining populations of invasive species.
9. Determine the effectiveness of alternate compliance technologies in killing or removing ballast organisms and preventing established populations of invasive aquatic species.

E. Ballast Water - ecosystem effects

1. What methods, data, and models are required to assess the risk of ballast water pathways and trade partner sources associated with invasive species introductions?
2. Determine the ecosystem vulnerability to invasive species of the Gulf ports and adjacent inland waters.
3. Determine similar vulnerabilities for aquaculture and water garden imports, handling organisms and preventing established populations of invasive aquatic species.

F. Shrimp viruses

1. Develop best management practices to identify and control shrimp viruses during delivery of seafood.
2. Develop simple probes to determine the presence/absence of shrimp viruses.
3. Establish a monitoring protocol/program to test for the presence of virus in wild shrimp populations.

1. Introduction

The Gulf of Mexico (Gulf) comprises approximately 600,000 square miles of ecologically and economically rich, interconnected ecosystems which are increasingly impacted by physical, chemical, and biological stresses directly related to human activity. Anthropogenic pollutants enter the Gulf waters primarily through the coastal watersheds. The Mississippi River Drainage Basin, which encompasses approximately two-thirds of the contiguous U.S., is the largest watershed influencing the Gulf. Atmospheric deposition serves as an additional source of pollutants to Gulf waters. Environmental problems are magnified by the relatively closed circulation of the Gulf and the numerous and sensitive habitats which border it.

General signs of diminishing environmental quality include debris on shorelines, beach closures, reduced water clarity and quality, fish consumption advisories, shellfish bed closures, and fishing bans. More quantitative evidence of environmental degradation was provided by monitoring of the Louisiana Province (Rio Grande, TX to Anclote Key, FL) estuaries during 1991-94. This effort determined that 25±6% of sediments in the province displayed poor biological conditions, measured by benthic community structure, and 14±7% of the area was characterized by poor water clarity, the presence of marine debris, and elevated levels of fish tissue contaminants (Macauley et al. 1999). Based on this assessment as well as data provided by the National Oceanic and Atmospheric Administration, the U.S. Geological Survey, and the U.S. Department of Agriculture, the overall condition of the Gulf Coast was described as “fair to poor” (USEPA 2001).

There is concern that increased human use of the watersheds and waters of the Gulf is affecting the overall quality of this important, large marine ecosystem. The population of the coastal counties of the Gulf has experienced significant growth. Between 1990 and 2000, there was a 16.6% increase - 1,300,958 more people - in the Gulf coastal counties. With these rapidly growing demands on the natural resources, we must develop a better understanding of the environmental problems and their causes so that practical and effective management/control alternatives can be developed, assessed, and implemented in a timely and credible fashion. These concerns led to the creation of the Gulf of Mexico Program (GMP). The GMP’s goals are to "facilitate the protection and restoration of the coastal marine waters of the Gulf and its coastal natural habitats; to sustain living resources; to protect human health and the food supply; and to ensure the recreational use of Gulf shores, beaches and waters in ways consistent with the economic well-being of the region."

This document describes the critical research needs required to understand major health and environmental issues in the Gulf, determine their cause(s), and to support environmental decisions in nine areas. The issues, related scientific uncertainties, and relevant research priorities are presented to assist federal, state, private, and public members of the GMP to incorporate these research needs in their annual research planning and budgeting exercises. This is not a stand-alone research planning or budget document.

The Research Needs Assessment was created in partnership with EPA’s Office of Research and Development (ORD), other Federal Agencies, the five Gulf States, and key stakeholders across the Gulf. The research identified reinforces a number of the critical needs identified in both the EPA, ORD Strategic Plan and Specific Research Plans. However, unlike EPA’s Plans, this document focuses on key issues and information gaps for the Gulf of Mexico ecosystem. While many of the Gulf needs overlap with national needs identified by EPA, this document identifies needs that are unique to the Gulf that fall under the purview of other Federal agencies as well as EPA.

The ultimate objective of this effort is to encourage and assist those organizations and institutions responsible for conducting environmental research to focus on the needs of the Gulf of Mexico ecosystem and to support those needs where possible. An important secondary objective is to assist Gulf scientists in preparing research proposals that support the critical scientific needs.

2. Major Health and Environmental Focus Areas

The health and environmental problems, and their causes, in the Gulf are numerous, complex, and often interconnected and the financial and technical resources required to understand and solve them are limited. For these reasons, the GMP has focused its available resources toward understanding and solving the most important health/environmental problems of the Gulf coastal zone. The following health and environmental Focus Areas and related objectives were identified as most important:

Nutrient Enrichment - to facilitate successful actions that will, through their combined effect, make advances toward protecting the waters of the Gulf from the deleterious effects of nutrient enrichment from all contributing sources and thereby enhance biodiversity, aesthetics, recreational opportunities, and economic benefits.

Habitat - to identify and champion candidate actions and/or projects that prevent, slow, stop or reverse losses of important Gulf habitats, enhance/restore the functions and values of degraded Gulf habitats, or protect rare or otherwise noteworthy Gulf habitats.

Public Health - to facilitate actions to reduce illnesses resulting from consumption of seafood harvested from the Gulf or from contact with its waters.

Invasive Species - to facilitate actions to reduce potential impacts on human health, important Gulf fisheries, and the economy of the Gulf region resulting from the introduction of undesirable, invasive organisms.

3. GMP Focus Teams

Four Focus Teams, one for each of the above Focus Areas, were organized to: (a) Identify major health/environmental problems related to their respective Focus Areas; (b) Define goals that, if accomplished, will assist measurably in fully understanding and correcting these problems; (c) Describe critical methods, data, or models needed to accomplish these goals; (d) Periodically evaluate alternative solutions to the problems as new data and information are generated; and (e) Recommend management practices to solve specific problems. Focus Team members include technical representatives from state and federal organizations, university scientists, public organizations and citizen groups, and industry.

The Focus Teams identify and annually update long-term objectives and annual performance goals required to understand and solve health and environmental problems of the Gulf related to their Focus Areas. Once endorsed by the GMP Policy Review Board, these goals and milestones provide direction to the Research Sub-Committee for recommending research priorities for the GMP.

4. GMP Research Subcommittee

The GMP organized the Monitoring, Modeling, and Research Committee (MMRC) as an operational committee to provide advice, identify requirements, and coordinate efforts on monitoring, modeling, and research issues for the GMP. The MMRC provides a forum for regular interaction among members of the monitoring, modeling, and research community to assist the GMP, especially its four Focus Teams, in the application of monitoring data, models, and research findings to support scientific assessments and decision-making in response to key health and environmental problems of the Gulf ecosystem. Three subcommittees, Monitoring, Modeling, and Research, were organized under the MMRC.

The Research Subcommittee of the MMRC works with the Focus Teams and assists in:

1. Defining priority research needs to substantially increase our understanding of major health and environmental problems of the Gulf Ecosystem, determine cause(s), and identify and assess environmental management/control options/remedies.
2. Communicating these needs to the research community;
3. Identifying and communicating past, current, and planned research activities in other programs that may meet these needs;
4. Seeking support from GMP Partners to meet GMP research needs;

5. Integrating research results to support comprehensive assessments;
6. Recommending major research milestones to the Focus Teams that will substantially increase our understanding of a health or environmental problem, its causes, and/or possible remedies;
7. Reviewing and ranking proposed applied research and assessment projects for GMP funding; and
8. Performing peer scientific review of technical products produced and published by the GMP.

Membership includes senior technical representatives from federal, state, business/industry, and Gulf state universities with responsibility for, or interests in, the Gulf. Technical capabilities of the subcommittee were buttressed by including the co-chairs of Expert Panels (see description below) as members and, through them, linking to technical experts in the Gulf. (Please see Appendix A for the names and parent organizations of the GMP Research Sub-Committee members).

5. Major Environmental Issues and Topics

Since the technical breadth of the Focus Areas is very broad, in most instances, the Research Subcommittee identified several specific Research Topics within each area for detailed study. For example, the Nutrient Enrichment Focus Area was subdivided into four Research Topics – Estuarine Hypoxia, Coastal Hypoxia, Harmful Algal Blooms, and Atmospheric Deposition (of nutrients); the Habit Focus Area was subdivided into Emergent Coastal Wetlands and Seagrasses; and Public Health was subdivided into Pathogens and Toxic Substances. The Invasive Species Focus Area was not subdivided.

The Research Subcommittee reviewed reports from previous efforts, e.g., the May 1993 Gulf of Mexico Marine Research Plan (Gulf of Mexico Marine Research Program, 1993), to further characterize the research requirements for each Focus Area/Issue. The Subcommittee also reviewed the research planning efforts of the cooperating federal and state partners to identify candidate research needs. The Focus Teams and the Research Subcommittee confirmed the importance of these Research Topics, using criteria to assess the magnitude of potential health & environmental effects such as:

1. Known or potential severity to human health or ecological health,
2. Time scale over which the effect might occur,
3. Ease with which the effect could be reversed,
4. Level of human or ecological organization impacted (e.g., individuals, populations, communities), and
5. Geographic scale of the effect.

Through this process, nine Research Topics (Table 1) were identified as important and have become the organizing themes around which Technical Expert Panels were organized and research/assessment objectives and research priorities developed.

6. Technical Expert Panels

Each Technical Expert Panel consisted of recognized subject matter experts, primarily from Gulf states, and was co-led by one state and one federal expert (see Research Topics which follow for names and affiliations of expert panel representatives). The Expert Panels were asked to describe the problem area(s) related to each Research Topic and to assess the state of the science regarding our understanding of each problem, its causes, and options for addressing each problem. Then, identify the major unknowns requiring research to provide the science or tools needed by environmental managers to assess, understand, or take action to address the problems. Finally, identify the major, related, scientific uncertainties as testable scientific hypotheses or scientific questions, and rank them (research needs) according to the magnitude of uncertainty they would resolve. This effort led to a well defined description of the research priorities for the Gulf Ecosystem. (Note: research needs were not prioritized for all research topics)

The specific research requirements to address these unknowns were identified and prioritized, in part, on the following factors:

1. Breadth of applicability of the research,
2. Extent to which the research will facilitate or improve risk assessment or risk management,
3. Size of the anticipated user community for the proposed research product,
4. Degree to which the problems, source(s), and risk(s) have been characterized to develop risk management options,
5. Existence and acceptability of available risk management options,
6. Degree to which new or improved technical solutions might prevent or mitigate the risk efficiently, cost-effectively, and in a manner acceptable to stakeholders; and
7. Potential for research collaboration among the GMP Partners.

The desire was to provide sufficient level of detail in defining research needs to enable the GMP to solicit research support from partner members. This was a major responsibility of the Expert Panels, working with the respective focus teams.

7. Research Priorities for the Gulf

The Expert Panels were guided by the following approach to identify and describe the Research Priorities for the Gulf:

1. Define the research priorities in terms of the strategic goals of the GMP (Protect public health and the food supply; Maintain and improve Gulf habitats that support living resources; and Maintain and enhance the sustainability of Gulf living resources) and the important health and environmental issues that were identified as the focus for achieving those goals. The GMP had identified four Focus Areas (Habitat, Nutrient Enrichment, Human Health, and Invasive Species). Nine Research Topics were identified as high priority in meeting the GMP strategic goals.
2. For each Research Topic, describe the most important objectives related to meeting the strategic goals of the GMP.
3. For each objective, define the major uncertainties in fully understanding the problem(s), conducting hazard assessments, and recommending remedial actions to correct the problem(s).
4. Describe the ongoing and planned research that addresses, at least in part, the major uncertainties.
5. Identify the unmet research needs (major uncertainties that are not adequately resolved by ongoing or planned research).

The research priorities that have been identified in FY2003 for each of the nine Research Topics follow in the research needs sections below. Each section is organized using a format that corresponds to the steps mentioned above and presents the un-met research needs for that Research Topic. These research needs should be considered by Gulf environmental organizations as important projects for funding support. It is anticipated that these un-met research needs will also be used by the GMP Partners and the research community as guidance for developing their research programs for the Gulf Ecosystem.

Table 1. Gulf of Mexico Focus Areas and Research Topics
Nutrient Enrichment Focus Area Goals and Objectives of Focus Team: Protect the waters of the Gulf from the deleterious effects of nutrient enrichment, from all contributing sources, and thereby enhance biodiversity and aesthetic, recreational and economic benefits.
Research Topic 1: Estuarine Hypoxia Research Topic 2: Coastal Hypoxia Research Topic 3: Harmful Algal Blooms Research Topic 4: Atmospheric Deposition
Habitat Focus Area Goals and Objectives of Focus Team: Identify and champion candidate actions and/or projects that prevent, slow, stop or reverse losses of important Gulf habitats; enhance/restore the functions and values of degraded Gulf habitats; or protect rare or otherwise noteworthy Gulf habitats.
Research Topic 5: Emergent Coastal Wetlands Research Topic 6: Seagrasses
Public Health Focus Area Goals and Objectives of Focus Team: Facilitate actions to reduce human illnesses resulting from: consuming fecal pathogens in shellfish, consuming naturally-occurring pathogens in shellfish, consuming marine biotoxins in shellfish, non-consumptive exposure to marine biotoxins, exposure to pathogens through recreational contact, and exposure to toxic substances in Gulf seafood.
Research Topic 7: Public Health - Pathogens Research Topic 8: Public Health - Toxic Substances
Invasive Species Focus Area Goals and Objectives of Focus Team: Facilitate actions to reduce potential impacts to human health, important Gulf fisheries, and the economy of the Gulf region resulting from the introduction of undesirable, invasive organisms.
Research Topic 9: Invasive Species

8. Inventory of Current and Future Research

Two parallel approaches will be pursued to define which of the research needs are being effectively addressed by current research activities or planned, budgeted research to be initiated in 1-3 years. The first approach will be accomplished by the Research Sub-Committee who will provide a comprehensive update of this needs assessment document an updated review of the research needs every five years. A second approach is through maintenance of a public database of ongoing and planned research in the Gulf region (http://www.masgc.org/rschinvn/research-inventory.htm) developed by the Mississippi-Alabama Sea Grant Consortium. Information regarding research in the four Focus Areas (Nutrient Enrichment, Habitat, Public Health, and Invasive Species), requested from scientific organizations and university departments, include: Project Title, Agency/ Organization, Points-of-Contact, Researchers, Starting and Ending Dates, Mission, Update. This database is updated on an annual basis. Collectively, these two approaches should identify the majority of the current and planned research relevant to the selected Focus Areas of the GMP.

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10. Nutrient Enrichment Focus Area -Estuarine Hypoxia Research Topic

Description of the Problem: Over one-half of the estuaries in the Gulf of Mexico (Gulf) exhibit moderate to severe dissolved oxygen depletion (hypoxia/anoxia), one of the key indicators of 'ecosystem health'. While anthropogenic nutrient over-enrichment is perceived to be a primary cause of hypoxia/anoxia, the estuaries of the Gulf display significant diversity in freshwater discharge, residence time, and stratification which impart varying susceptibility to nutrient loading that confound a simple cause and effect relationship.

Overview and Importance: Over the past several decades there has been increased concern about the negative effects of anthropogenic nutrient over-enrichment on estuarine and coastal ecosystems, a process often referred to as 'eutrophication'. While there is evidence that estuarine eutrophication is widespread in United States (82 of 122 estuaries were found to exhibit moderate to high levels eutrophication: Bricker et al. 1999), there are large differences in: (1) the sources of nutrients, (2) the biological responses to and indicators of nutrient over-enrichment, and (3) the degree of susceptibility to nutrient over-enrichment, for different estuaries.

While historically both point and non-point sources of nutrients have been important contributors to anthropogenic nutrient inputs to estuaries, a large percentage of point source nutrient inputs (e.g. municipal and industrial discharges) have been regulated considerably over the past 30 years. During this time, however, non-point source nutrient inputs (e.g. agriculture, atmospheric and septic tank inputs) have increased in most watersheds, particularly for nitrogen (N). As a result, both the concentration and loading of nutrients has increased in many systems.

Unlike many other anthropogenic pollutants (e.g. organic contaminants and metals), the negative effects of nutrient over-enrichment can not be measured in terms of increased body burden or LD-50s, Lethal Dose-50, of indicator organisms. As a result, the expression of eutrophication is assessed indirectly, most often by quantifying one or more of the following factors: (1) chlorophyll-a concentration, (2) epiphyte overgrowth of seagrasses, (3) nuisance macroalgae density, (4) loss of submerged aquatic vegetation, (5) the presence of nuisance/toxic algae, and (6) the presence of hypoxic/anoxic conditions (Bricker et al. 1999). However, such assessments are often compromised by the fact there is a great natural variance between different estuaries. For example, nuisance macroalgae (potential "weed" species, e.g., Cladophora and Ulva) are often naturally occurring but can rapidly increase biomass production following nutrient enrichment. In cool-temperate estuaries on the coast of Maine large brown algae (i.e., kelps such as Laminaria) provide important habitats while estuaries along the Gulf coast have naturally had varying densities of seagrasses, independent of the degree of anthropogenic nutrient loading to which they have been exposed.

In addition, the susceptibility of estuarine ecosystems to nutrient over-enrichment is in a large part regulated by the physical, geomorphologic and latitudinal characteristics of the estuary. For example, freshwater residence time, vertical salinity/density stratification, bottom depth and topography and seasonal temperature patterns will all affect the response(s) of an estuarine ecosystem to nutrient inputs (Pennock et al. 1999). As a result, ecosystem production and 'health' may be positively or negatively affected by the same level of nutrient loading, depending on the susceptibility of the system to loading. For example, Nixon (1980) observed a general pattern of increase in estuarine production with increasing freshwater input. In contrast, increased nutrient loading to the Chesapeake Bay and the Louisiana-Texas coast have been associated with negative food web alterations and hypoxic/anoxic events (Officer 1984; Rabalais et al. 1994).

Estuarine Hypoxia in the Gulf: Depending on the estuarine characterization scheme used, the Gulf contains between 32 (Bianchi et al. 1999) and 37 (Bricker et al. 1999) estuaries. One of the striking features of these estuaries is their diversity in geomorphologic (Schroeder and Wiseman 1999), physical (Solis and Powell 1999) and biogeochemical (McKee and Baskaran 1999; Turner and Rabalais 1999; Pennock et al. 1999; Twilley et al. 1999) characteristics. Of particular importance to hypoxia is the broad variability among Gulf estuaries in total nitrogen loading rates (1-5000 mM m-2 y-1; Turner and Rabalais 1999), vertical salinity stratification (vertically well-mixed to >10 ppt change over a 0.5 m depth in the water column; Schroeder and Wiseman 1999), and freshwater residence time (3-350 days; Solis and Powell 1999). As a result of these factors and the warm-temperate climate that supports high metabolic rates year-round, the potential for the formation of hypoxic/anoxic bottom waters is great.

Several studies provide assessments of estuarine hypoxia in the Gulf (Whitledge 1985; Rabalais 1992; Bricker et al. 1999; Ritter and Montagna 1999). Each of these studies found significant summertime bottom oxygen depletion in numerous estuaries. Interestingly, however, is the fact that there is not a strong congruence between the conclusions drawn for many of the estuaries in the different assessments. These differences may at times result from changes in these systems during the 15-year range between these assessments; however, it is also apparent that the lack of quantifiable data analyzed over similar spatial and temporal scales has contributed to these differences.

Overview of the Technical Expert Panel Discussions: During our panel discussions, the Technical Expert Panel (TEP) acknowledged the importance of 'hypoxia/anoxia' as a regulator of 'ecosystem health' and as an indicator of nutrient over-enrichment in estuaries of the Gulf . We were, however, surprised by the lack of congruence from the several Gulf-wide assessments of hypoxia over the past 20 years. We believe that this variance is due in large part to the fact that these assessments were frequently based on a 'presence/absence' scheme rather than quantifiable data sets that were spatially and temporally robust. It is also clear that the large range of geomorphologic and physical characteristics in Gulf estuaries will result in different factors being dominant forcing functions in different estuaries.

The TEP also expressed concern that the presence of hypoxia/anoxia is frequently taken, a priori, as an indicator of degradation in estuarine 'ecosystem health' when, in fact, conditions in many Gulf estuaries (e.g. low tidal energy, strong vertical stratification and warm temperatures) are conducive to oxygen depletion even in the absence of increased anthropogenic nutrient loading. This problem is made more acute by the fact that oxygen saturation values during the summer are often near the accepted level of concern (5 mg/l) established for cool-temperate estuaries of the Atlantic and Pacific coasts. In addition, the panel felt that the well-documented and widespread occurrence of hypoxia/anoxia in the Mississippi River Plume has diluted efforts to understand and manage the effects of nutrients on the health of Gulf estuaries, despite the fact that a large percentage of the population lives in close proximity to these systems.

As a result, there was strong consensus that protocols/techniques must be developed that can distinguish between 'natural' and anthropogenic hypoxia/anoxia events and be able to quantify 'nutrient susceptibility' for Gulf estuaries. For example, continuous monitoring instruments may provide increased temporal sampling while at the same time furnishing information on predawn oxygen concentration and day/night variability that might prove to be valuable 'indicator' parameters.

Major Research Needs: These discussions led to a consensus on the following research needs.

1. Develop a quantitative assessment of estuarine hypoxia/anoxia for the Gulf that provides a spatially and temporally robust framework describing hypoxia/anoxia in these systems.
   a. What information is needed to better assess the extent of hypoxia in Gulf estuaries?
   b. What are the major uncertainties associated with available data to characterize the frequency, duration, extent, and intensity of hypoxia in Gulf estuaries?
   c. How should hypoxia be defined for the range of estuarine types in the Gulf?
   d. What are the most appropriate measures of dissolved oxygen, e.g., absolute concentration or a measure of saturation?
2. Develop an index that will improve the assessment of 'estuarine susceptibility' to nutrient enrichment for Gulf estuaries. In addition to 'nutrient loading', this index must incorporate the roles of residence time, vertical stratification and other physical factors.
   a. What are the most useful classification systems (e.g., flushing/stratification-based, geomorphologically-based, etc…) across the spectrum of Gulf estuaries that reduce variability in assessment of hypoxia susceptibility?
   b. What is the level of predictability of the various classification systems?
   c. What might be a cascading suite (e.g. change in phytoplankton community dominance, development of macro-algal blooms, etc…) of early biotic-based warning indicators of hypoxia formation?
   d Are there any biochemical early warning indicators of impending hypoxia formation?
   e. Assess the evidence that characterizes the occurrence and magnitude of predawn hypoxia conditions in Gulf estuaries?
   f. Does predawn hypoxia tend to occur regularlyunder a suite of similar environmental conditions?

g. Does the pattern in the variability of hypoxia at smaller scales predict the intensity, frequency, duration, and physical extent of hypoxia at larger scales?

3. Determine the importance of anthropogenic versus 'natural' processes in the formation of hypoxia/anoxia in Gulf estuaries.

a. What is the evidence that hypoxia occurred or continues to occur naturally in Gulf estuaries?

b. What roles do physical processes play in the onset of hypoxia, e.g., water circulation, residence times, freshwater inflow, and stratification?

c. Which nutrients or combinations are most strongly linked as a contributing factor (s) to hypoxia?

d. How do anthropogenic sources (e.g., wastewater treatment plant effluent) vs natural allochthonous and autochthonous dissolved organic matter affect the magnitude and species composition of algal production with potential effects on hypoxia; e.g., the more phytoplankton organic matter passed up the food web through the copepod-to-fish pathway would leave lessor amounts available to the microbial loop to effect a greater level of hypoxia?

e. Under what conditions might bacteria out-compete autotrophic phytoplankton for nutrients and thereby limit increased in situ organic carbon formation by photosynthesis?

f. Which estuaries provide the potential for documenting sedimentary paleo-redox conditions?

g. What is the relative role of allochthonous organic matter contributing directly to BOD?

h. What are the relative roles of external nutrient supplies versus internal recycling to maintain primary production?

i. Are there conditions (e.g. turbid or blackwater systems) where light limitation serves to increase or decrease hypoxia formation?

j. Just because an estuary has a naturally-low DO concentration, due to high temperature and salinity, does not mean that wasteloads are not a problem/concern. Low natural DO solubility means the assimilative capacity for pollutants is low, so wasteloads should be limited more than for receiving waters with naturally higher DO solubility. More research needs to be done on the implications of naturally-low DO solubility due to high temperature and salinity for managing wasteloads (including nutrients).

Cautionary note: *For Objectives # 2 & #3 it is important to note that it is desirable to consider the relative change in spatial area and duration as indicators of change where appropriate, particularly in contrast to merely presence or absence.*

4. Assess how the frequency, duration and intensity of hypoxia/anoxia events affect biological communities across the broad gradient of Gulf estuaries.

a. Which migratory species are at greatest risk to life cycle completion because of hypoxia formation? Do these vary with the 'type/class' of estuary?

b. Can macrofauna community biomass and structure serve as an indicator of conditions favoring hypoxia?

c. Is there a relationship between the occurrence of hypoxia and changes in the food web between benthic organisms (e.g. oysters) and planktonic grazers (e.g. jellies, zooplankton and fish)?

5. If estuarine hypoxia is a problem in Gulf estuaries, determine what management practices would have the greatest effect in minimizing these conditions.

a. What are the relative effects of nutrient loading, nutrient ratios, bathymetric modification (e.g., dredging), regulation of freshwater input, etc. on hypoxia/anoxia in Gulf estuaries?

b. What are the anticipated effects of climate change on estuarine hypoxia in the Gulf?

Research Priorities: All of the research priorities have relevance for natural resource decision makers. Team members recommend that all research objectives be given consideration as resources become available but recognize that resources will likely limit implementation of the full suite of objectives. Therefore, several objectives are especially important for earliest consideration. The following objectives were selected from the list with a brief rationale for their early inclusion in a research program designed to reduce critical uncertainties and improve risk management decisions regarding Gulf estuarine hypoxia.

#3. Determine the importance of anthropogenic versus 'natural' processes in the formation of hypoxia/anoxia in Gulf estuaries. This objective is singled out because it is critical to determine early in the decision process which estuaries possibly experienced hypoxia naturally. This could influence the level of expectations and nature and extent of any management actions designed to reduce hypoxia through management activities. Although the objective does not list the possibility of past management actions that may have reduced the frequency, duration, and magnitude of hypoxia that occurred naturally, that possibility exists, especially for smaller estuaries where intervention through engineering efforts may have occurred, e.g., opening or deepening channels at the passes to the open Gulf waters. The converse is also important to know–Did any earlier management efforts to reduce hypoxia exacerbate this problem?

#2. Develop an index that will improve the assessment of 'estuarine susceptibility' to nutrient enrichment for Gulf estuaries. This objective ranks very high. Development of a Gulf estuarine 'susceptibility index' would help decision makers determine where to focus remediation resources and protect estuaries that are presently minimally ecologically impaired.

#4. Assess how the frequency, duration, and intensity of hypoxia/anoxia events affects biological communities across the broad gradient of Gulf estuaries. One of the first questions frequently asked by various stakeholders is the "so-what question" - so the estuary experiences hypoxia, does it affect negatively recreational and commercial species or other aesthetic values that have important economic value? The biological connection must be made to hypoxia regarding various land use activities that cause an increase in hypoxia, especially anthropogenic increases over naturally occurring hypoxia. For example, although submerged aquatic vegetation (SAV) had markedly declined in Chesapeake Bay by the time of initiation of the Chesapeake Bay Program in 1977, stakeholders wanted to know whether the decline was to any degree a natural event. This question stimulated early work on collection of sediment cores and biostratigraphy to determine if the SAV decline had an earlier antecedent.

We consider Research Objective # 5 to be in a virtual tie with Objective # 4. The rationale is that an evaluation of the relative effects from different "sources" of nutrients contributing to hypoxia would allow those estuaries where the characterization has been completed to more effectively move forward in addressing the source issue without waiting.

Milestones for Research Program Implementation and Integration:

1. Workshop on Estuarine Hypoxia. A workshop is needed to assess the feasibility of developing a provisional classification system that would facilitate determination of the power of extrapolation of hypoxia-based research findings across one or more Gulf estuarine systems. The assumption is made that resources to implement a Gulf-wide estuarine research hypoxia program are limited and the utility of extrapolation of research findings would be well received by decision makers and scientists. The most robust framework or model for assessment of extrapolation lies in the ability to develop a 'susceptibility index' for Gulf estuaries. However, that effort may require several years to develop and field verify the scientific robustness and predictability of such a framework as it may require the passage of natural events, e.g., major

freshets, droughts, to adequately confirmpredictions. We recommend that:

a. As soon as resources become available, hold workshop and produce report within 2 months of workshop on estuarine classification/extrapolation relative to hypoxia research questions. Approaches to estuarine classification and susceptibility are discussed in Chapter 6–What Determines Susceptibility to Nutrient Over-Enrichment?, In: National Research Council. 2000. Clean Coastal Waters–Understanding and Reducing the Effects of Nutrient Pollution, National Academy Press, Washington, D.C.

b. Develop criteria at the Workshop for which estuaries will receive priority study regarding hypoxia. Examples of criteria might include: serve as critical nurseries for highest number of endangered species, highest secondary biological productivity per unit area with greatest economic value, most unique system within a class, highest likelihood of success in reducing hypoxia, and least impaired now but most vulnerable estuary to an increase in hypoxia because of future demographics and land use. Criteria development for this activity should involve scientists and resource managers. The final priority should be made by managers with two to three scientists present as resource individuals to answer technical questions.

2. <u>Plan for Assessment of Hypoxia in Gulf Estuaries</u>. To maintain program integrity in the face of budget uncertainties, it is important to perform the following activities. In parallel to the criteria workshop described above, another workshop is needed to prepare a research, modeling, and monitoring plan to integrate experimental research, ambient empirical research and monitoring and modeling, events of opportunity, e.g., freshet effects on strength of hypoxia vs nutrient loading, and long-term monitoring, e.g., data buoys, satellites, fixed wing aircraft with environmental sensors. These efforts should be integrated into a research management framework for candidate estuaries where hypothesis-focused research will be conducted. We recommend that:

a. As soon as resources become available, hold a workshop to assess research, modeling, and monitoring activities being conducted or planned to be initiated by various Federal, State environmental agencies, universities and private organizations for relevance to the Gulf estuarine hypoxia program. Correlate findings from this assessment with management information and data needs to determine if and where largest data-gaps occur in candidate estuaries.

b. Develop a plan to fill data gaps that are identified at the assessment workshop.

Note of caution: Analyses described above will involve nutrient budgets. However, the accuracy and precision of such budgets, whether existing or to be developed, should be evaluated in terms of component uncertainties. Budgets with high uncertainties can be misleading. Expensive resource management decisions often require more than so-called "back of the envelop" budget estimates.

3. <u>Data Management Plan for Hypoxia in Gulf Estuaries</u>. Develop a database management plan for Gulf estuarine hypoxia research that includes metadata. This plan should be web-accessible and completed by fall 2001.

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11. Nutrient Enrichment Focus Area - Coastal Hypoxia Research Topic

***Note**: In recognition of the extensive past efforts in assessing the scientific knowledge and uncertainties related to coastal hypoxia conducted by the Committee on Environment and Natural Resources (CENR), and for consistency, the materials contained in this research needs document were abstracted from "An Integrated Assessment of HYPOXIA in the Northern Gulf of Mexico" (CENR, 2000). Reference should be made to this and referenced predecessor documents for greater detail.*

Description of the Problem: The largest hypoxic zone in U.S. coastal waters is located in the northern Gulf of Mexico on the Louisiana/Texas continental shelf. The affected area, about the size of the state of New Jersey, has increased since regular measurements began in 1985. Hypoxic waters are distributed from shallow depths near shore (4-6 meters) to as deep as 60 meters and are most prevalent from late spring through late summer. Hypoxia occurs mostly in the lower water column but encompasses as much as the lower half to two-thirds of the water column.

Overview and Importance: The shallow continental shelf area of the Gulf affected by hypoxia shows signs of hypoxia-related stress, including low abundance of fish and shrimp and distinctly different benthic communities. While the ecological effects of this hypoxic zone are not well understood, potential impacts could include a precipitous decline in ecologically and commercially important fish and shellfish species.

Research results strongly indicate that hypoxic conditions in the northern Gulf of Mexico are caused primarily by excess nutrients delivered to Gulf waters from the Mississippi-Atchafalaya River Basin (MARB) in combination with stratification of Gulf waters. Improvements in farming practices, riparian and wetland restoration, and river-flow management may mitigate hypoxia in the Gulf but current factors (e.g., population growth and food production) which drive hypoxia are projected to intensify.

Research Needs: While a great deal of research and monitoring results were incorporated in the CENR Integrated Assessment (CENR, 2000), uncertainties remain in the scientific analyses regarding the nature of the problem, its cause(s), and effective remedial actions. It is recommended that a comprehensive program of monitoring, interpretation, modeling, and research be coupled with development and application of nutrient management strategies.

An effective research strategy is integral to an adaptive management framework. Coordinated research efforts improve monitoring designs, support the interpretation of monitoring output, and increase the predictive power of models and other assessment tools used in the management process. For large and complex systems such as the MARB and the northern Gulf of Mexico, monitoring and research should be integrated using holistic models that simulate our understanding of how the overall system functions and how management practices can be most effectively implemented. River monitoring data should be integrated with offshore ecological and oceanographic data on appropriate time scales. An effective modeling framework would include models that simulate:

1. transport and transformation of nutrients (nitrogen, phosphorus, and silica) from natural, urban, and agricultural landscapes to ground water and surface waters;
2. inputs and outputs of nutrient flow throughout the landscape to improve estimates of nutrient mass balances;
3. biogeochemical cycling and water quality effects of those nutrients on river ecosystems within the drainage basin;
4. oceanographic and climatic influences on those nutrients and their impacts on Gulf productivity as they leave the Mississippi-Atchafalaya River system;
5. impacts of increased nutrient flux on productivity in the northern Gulf of Mexico ecosystem, including commercially and recreationally important fisheries; and
6. three-dimensional coupling of biological and physical processes in the Gulf ecosystem influenced by the Mississippi River discharge.

Research Needs for the Gulf of Mexico:

Research needs fall into two categories: (1) immediate priorities that are essential for designing near-term management actions, and (2) longer-term priorities that fill critical gaps in understanding as well as guide efforts to mitigate and control the effects of hypoxia and excess nutrients.

Immediate Research Priorities

1. Past, current, and potential impacts of hypoxia on both commercially and economically important species and ecosystems
   a. retrospective analysis based on sediment cores and existing data bases
   b. better understanding of the effects of other factors that affect the ecological health and fisheries of the Northern Gulf of Mexico
2. Dynamics and timing of transport of nitrogen and other nutrients from the landscape into streams and coastal waters
3. Geographic location and design criteria for wetlands and other strategies (e.g., riparian zones) for effective nitrate reduction
4. Influence of on-farm practices on transport of nitrogen and other nutrients into streams
5. Better methods to intercept agriculture nutrients between the fields and ground water and adjacent streams
6. Effectiveness of current and potential policies and actions to reduce nutrient loss on a basin scale.

Longer-Term Research Priorities

1. Nutrient cycling and carbon dynamics across the MARB and relationship of site-specific actions to Basin-scale effects
2 Characterize mineralization and immobilization processes to better understand the amount and forms of nitrogen in the soil reservoir and to develop strategies to minimize leaching of nitrate into streams
3. Quantify denitrification and nutrient retention rates in streams and in Gulf sediments and compare to that achieved in riparian zones and wetlands
4. Relationships among nutrient fluxes, nutrient ratios, and nutrient cycling on the continental shelf of the Gulf of Mexico
5. Amount and composition of atmospherically deposited nitrogen in the Gulf
6. Relationship between large-scale climate patterns and impacts on river flows, nutrient flux, and flow dynamics on the continental shelf
7. Role of flood prevention and control methods in retaining nitrogen within the MARB
8. Better understand nutrient cycling in the deltaic plain to guide potential changes in land management activities
9. Aggregated analysis of direct (drinking water protection) and indirect (recreational improvements) improvements in water quality for the MARB, as a whole.
10. Potential economic effects of hypoxia on the ecology of the Gulf, including impacts to biodiversity and nonmarket-valued ecosystem goods and services.
11. Better estimates of the economic benefits to agricultural producers from reduced fertilizer use and to society from nitrogen management or reduction strategies

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The CENR commissioned six research teams to critically evaluate various aspects of Gulf coastal hypoxia and analyze and summarize technical information regarding the problem and its cause(s). The CENR, "*An Integrated Assessment of Hypoxia in the Northern Gulf of Mexico*," drew heavily from the results of their collective efforts. The research teams and their members are listed below.

Characterization of Hypoxia

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Flux and Sources of Nutrients in the Mississippi--Atchafalaya River Basin

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Effects of Reducing Nutrient Loads toSurface Waters within the Mississippi River Basin and Gulf of Mexico

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Reducing Nutrient Loads, Especially Nitrate--Nitrogen, to Surface Water, Ground Water, and the Gulf of Mexico

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12. Nutrient Enrichment Focus Area - Harmful Algal Blooms Research Topic

Description of the Problem: Harmful Algal Blooms (HABs) are now common events in the Gulf of Mexico (Gulf) and worldwide. HABs have caused large-scale aquatic mortalities, altered coastal ecosystem structure and function, impacted coastal economies, and threatened human health. Although knowledge concerning HABs in freshwater, estuarine, and marine ecosystems has increased over the last several years, scientific uncertainties regarding many aspects of HABs continues to hinder attempts to develop and implement effective management programs for the multitude of problems associated with these species and their toxins.

The expansion of HABs and their impacts in coastal waters of the Gulf, U.S., and worldwide over the last two to three decades has been well documented (Hallegraeff, 1993; Anderson, 1995; Steidinger et al., 1999). Realization of the scope of the problem is reflected in the growing number of publications on various aspects of HABs, in the number of local, national and international meetings, conferences, and workshops, in the development of Federal and State funding initiatives, and more recently in passage into law of the Harmful Algal Bloom and Hypoxia Research and Control Act of 1998.

During any particular year, one or more HAB events are likely to occur in Gulf freshwater, estuarine, or marine waters. More than 60 known toxic or potentially toxic microalgal species, including the Texas brown tide species, are known to exist in Gulf waters, but currently the effects of only a few species are the most visible and real threat to human health, aquatic resources, and coastal economies (Dortch et al., 1999; Steidinger et al., 1999). Yet, since we know little about the biological and physicochemical factors or ecological conditions that promote blooms of some toxic species and not others, there is a growing need for studies on several other species and toxins that pose emerging risks (i.e., toxins in drinking water sources) and dozens of other species which are not current threats but which might create toxic blooms under certain conditions.

By far the most problematic species is the red tide dinoflagellate, *Karenia brevis*, which produces brevetoxin and causes neurotoxic shellfish poisoning (NSP). Brevetoxin has long been implicated as a causative factor in mass mortalities of fish, birds, and marine mammals, yet the effects of acute and chronic exposure to brevetoxin on reproduction and population dynamics of the affected species are largely unknown. Risks to human health are associated with ingestion of contaminated seafood, direct contact with seawater, and inhalation of aerosols. Economic losses from *K. brevis* blooms are difficult to assess accurately, but have been estimated at approximately $15 to 25 million per event in some areas.

In contrast to the Gulf-wide threat of K. brevis blooms and NSP, other HAB species and their toxins currently are more localized problems. These include *Pseudo-nitzschia* and domoic acid in Louisiana, okadaic acid in Louisiana and Alabama, and the emerging threat of cyanobacterial hepatotoxins in lakes and freshwater impoundments Louisiana, Florida, and probably the other Gulf states as well. *Pfiesteria*-related events along the Atlantic coast during the 1990's emphasized the need for better information on the occurrence and distribution of *Pfiesteria*-like species in the Gulf and on environmental or ecological conditions that may promote toxic events. Finally, increasing numbers of mariculture facilities and their products may be at risk from toxic outbreaks in the facilities, and in some cases these operations may increase the incidence and severity of some, but not all HABs, depending on the location, hydrographic conditions and rearing practices.

The research needs are recommended with consideration to existing research underway, particularly the substantial financial support provided by the Ecology of Harmful Algal Blooms, ECOHAB-Florida program. Dr. Karen Steidinger, Florida Marine Research Institute, FMRI, St. Petersburg, FL is the Principal Investigator of this research effort which incorporates numerous technical experts and HAB-related research topics.

The reader is referenced to a national HAB research plan prepared by the National Sea Grant College Program entitled, "Prevention, Control and Mitigation of Harmful Algal Blooms." It is available at http://www.nsgo.seagrant.org/research/hab/sig_hab_plan.html. There are similarities and differences in research needs compared with information presented here. Differences are largely due to a national versus a regional focus.

Major Gulf Research Needs and Objectives:

Estuarine and Marine HABs

1. Develop a list of HAB investigator/facility expertise and capabilities. Identify those facilities capable of, and willing to provide analyses of Gulf of Mexico, GOM, samples, such as toxin analysis, species identification, etc. (include cost per sample and number of samples willing to analyze, and how frequently), as well as provide assistance to event response efforts.
2. Develop the capabilities for routine monitoring of HABs and environmental condition.
   a. Develop standardized monitoring designs and protocols to determine the distribution and abundance of specific HAB species.
   b. Develop standardized monitoring designs and protocols to detect bloom initiation, development, movement, and termination to determine environmental and ecological conditions, and to protect public health.
   c. Develop and/or enhance state-by-state contingency plans and training for rapid response to HAB events.
   d. Develop reliable and rapid chemical (or other non-mouse) assays for HAB toxins for use in field monitoring.
   e. Develop and enhance satellite and aircraft remote sensing capabilities to monitor and track blooms at local to regional scales.
   f. Develop an integrated web-based forum for sharing of HAB monitoring data in a standardized format.
3. Develop the capabilities to predict the occurrence of HABs
   a. Establish clonal cultures of HAB species from different geographic areas around the GOM in order to characterize:
      - toxin profiles, other bioactive compounds, and effects of environmental conditions on toxin production.
      - morphological variation, physiological tolerances, nutritional requirements, and responses to environmental conditions.
      - life history stages and genetic strain variability in order to evaluate the source of inoculum for blooms and reoccurrence of blooms.
   b. Develop methods, models, and data to determine the onset and movement of HABs, and potential linkages (direct and indirect) between anthropogenic activities (i.e., nutrient enrichment, water diversions, land use practices, etc.), natural conditions and HAB occurrence.

c. Develop long-term monitoring programs which describe changing conditions in the Gulf offshore in order to understand changes in the Gulf which precede HAB development.

4. Develop epidemiological and epizootiological studies to assess exposure to and acute and chronic effects of algal toxins on public health and aquatic animals.

a. Develop standardized methods to identify toxins and toxin metabolites in humans and aquatic animals, including dead animals.

b. Develop acute and chronic dose-response relationships for humans and aquatic animals exposed to algal toxins in order to provide scientifically defensible guidance levels for protection of human and animal health.

c. Determine effects of toxin-induced mortalities on reproduction and population dynamics of affected species, including mortalities of eggs and larvae.

d. Determine effects of toxins on physiological function of different species, including effects on reproductive capability (sperm and egg production).

5. Determine the fate and effects of algal toxins in aquatic environments, including water, sediment, air, and food webs.

a. Develop standardized extraction, detection, and quantification protocols for algal toxins and metabolites in water, sediment, and animal tissue.

b. Assess accumulation and degradation on algal toxins in water, sediment and animal tissue.

c. Develop suggested methodology for evaluating impacts on biological communities in affected areas over the short-term following HAB events.

6. Evaluate the effects and effectiveness of potential mitigation, control, and prevention strategies to reduce ecological and public health impacts of HABs, and evaluate possible relationships to nutrient water quality standards development.

7. Continue and enhance public information and outreach programs.

a. Develop or enhance the use of the Internet for public information and data reporting.

b. Encourage and support States to foster appropriate public awareness.

c. Improve effectiveness of communication with media.

Toxic Cyanobacteria

1. Develop standardized monitoring designs and protocols to assess the distribution of toxic and nontoxic cyanobacteria strains in surface waters.
2. Develop epidemiological studies to assess public health risks associated with cyanotoxin-contaminated drinking water.
3. Determine whether aquatic animal mortalities in lakes heavily impacted by toxic cyanobacteria were caused by cyanotoxins.
4. Assess cyanotoxin accumulation in higher trophic level species and threats to human and animal health.
5. Determine the roles of nutrient enrichment and managed freshwater flow in bloom development.
6. Determine the fate and effect of cyanobacteria toxins from the source to the finishing water at the plant to the faucet in the private residence.

Mariculture

1. Develop guidelines for siting mariculture facilities in coastal waters that incorporates hydrographic conditions, water quality data, rearing practices, historical HAB events.
2. Develop monitoring guidelines for mariculture facilities that incorporates HAB information and water quality criteria.
3. Develop practical, cost efficient contingency plans to control or mitigate HABs should they occur in mariculture facilities.

Strategic Products:

1. A list of laboratories capable of identifying and responding to a HAB events.
2. Training on sampling methodology and identification of harmful algae.
3. Quantitative information on the biology of HAB species.
4. Capabilities for real time tracking of HABs.

5. A decision tree for state and local responses to HAB events.
6. Effective communication with the public and media about harmful algal blooms.
7. Predictive numerical model(s) of HAB initiation and transport.
8. Quantitative assessment(s) of HAB toxin effects on ecosystems, aquatic animals, and public health.
9. Practical, cost-effective management strategies to reduce or prevent HAB occurrences protect public health.
10. Management strategies aimed at reducing HAB events, reducing product loss, and thus increasing economic output at mariculture facilities.

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13. Nutrient Enrichment Focus Area - Atmospheric Deposition Research Topic

Description of the Problem: The Mississippi and Atchafalaya Rivers carry to the Gulf of Mexico each year 0.95 million metric tons of nitrate nitrogen in waters drained from the Mississippi River Basin. Every summer this nutrient load is thought to cause the development of a hypoxic zone the size of the State of New Jersey in the northern Gulf of Mexico (Goolsby, 2000). Moreover, continued population growth around the perimeter of the Gulf of Mexico has intensified the nutrient loading at the coastline where eruptions of harmful algal blooms and the threat of human pathogens pose a recurring public and environmental health problem. Atmospheric deposition has been recognized as a source of nutrients in the estuaries and coastal waters of the United States (NRC, 2000). Nitrogen loadings are due to both direct deposition to the water surface and indirectly from deposition to and subsequent transport from the watersheds associated with these water bodies, and may contribute up to 24% of the total nitrogen discharged by the Mississippi River to the Gulf of Mexico (Goolsby, 2000). The complexity inherent in understanding the multimedia nature of the air/water/land interfaces has made quantifying this source of water quality impairment a significant research challenge.

Overview and Importance: The coastal zone of the Gulf of Mexico is endowed with immensely productive habitats whose ecological functions enhance all of the Gulf's wildlife and fishery resources and provide important aesthetic and tourism opportunities. Impairment of the water quality is largely associated with nutrient over-enrichment, leading ultimately to the hypoxia events observed in the coastal zone of the Gulf of Mexico and possibly to harmful algal blooms. The contribution of the atmosphere to this over-enrichment has been estimated for many of the coastal estuaries (Castro et al, 2000) and estimates range from 15% to 40% of the total nutrient load.

Nationally, wet deposition is generally well characterized through monitoring data gathered by the National Atmospheric Deposition Program (NADP). (Lynch et al., 2000). Wet deposition is typically a source of nitrogen to the nutrient pool with nitrate (NO^{3-}), ammonium (NH^{4+}) and organic forms (poorly identified) providing the bulk of the species present. Dry deposition across the United States is not as well characterized as wet. The measurement of the amount of dry deposition is technically challenging and it is more difficult to spatially interpolate these measurements as they are land-use (location) specific. Relatively fewer sites across the U.S. regularly monitor for dry deposition, compared to the many sites monitoring wet deposition. Regional estimates of dry deposition are typically model-derived and verified from point observations. The nitrogen compounds may be either gas or aerosol and are comprised of the same nitrogen species found in wet deposition.

Deposition occurring directly to the water surface of estuaries and near-coastal waters may be estimated from air or rainwater nutrient concentration measurements transformed through chemical transport, meteorological, or observational models. Deposition occurring on the watersheds associated with each estuary can also contribute to the nutrient load affecting the estuary's waters. The deposition to the watershed surface can be estimated by the same methods used to determine direct deposition to the water. Once on the watershed, the deposited nutrients enter into biogeochemical cycles and become part of the non-point source load reaching the water bodies. The contribution from non-point source loads to the loading in the receiving water bodies is generally assessed using watershed models (NRC, 2000). Improved estimates of nutrient loading from atmospheric deposition will, of course, be evaluated in comparison to other pathways of nutrient loading which affect the northern Gulf, its near shore waters, and estuaries.

The distribution of nitrogen species in the lower atmosphere can be defined in terms of three steps on temporal or spatial scales; three terms will be used in this paper as follows. First, the local scale of 0.1 km to 100 km or a temporal scale of ~1 day; for example, urban nitrogen oxide (NO) concentrations decay within tens of km or less than one day (though nitrates and other reaction products may persist for several days.) A regional scale of 100 km to 1,000 km or a temporal scale of days to one week; for example some nitrates or ammonium sulfate aerosols atmospheric gradients decay over this scale. [Some references, e.g. Seinfeld and Pandis, 1998, may consider regional scale to extend for weeks.] The third scale of interest is the synoptic scale of 1,000 km to 5,000 km and its corresponding temporal scale of weeks. (A larger scale, "global" generally applies to trace materials which especially persistent in the atmosphere and can be carried more than 5,000 km or 10,000 km for a year, or possibly longer. However, for nutrient chemicals in sufficient quantities for direct eutrophic effects, the global scale generally does not apply.)

Major Goals and Milestones: The four **goals** reflect information considered necessary to achieve the overall goal of quantifying the contribution from atmospheric deposition to the Mississippi-Atachafalaya River Basin, estuaries and watersheds along the U.S. coast of the Gulf of Mexico and the northern Gulf waters to better assess total nutrient loads associated with Gulf hypoxic and anoxic events. Milestones characterize areas of scientific uncertainty that need to be resolved before a particular goal can be achieved. Research Needs describe individual research tasks that must be completed to resolve the scientific uncertainties expressed in by the Milestones.

Goal 1. Improve our ability to quantify the atmospheric nitrogen deposition, in terms of oxidized nitrogen, reduced nitrogen and dissolved organic nitrogen, to the Mississippi-Atachafalaya River Basin (MARB), to estuaries along the Gulf of Mexico and their watersheds, and to the waters of the Gulf of Mexico, especially the northern waters near the U.S. Atmospheric nitrogen deposition by indirect (to watershed) and direct (to water surface) pathways contributes 20% to 30% of the total nitrogen flux to the northern Gulf of Mexico, with the majority coming from indirect deposition to the MARB.

Milestone (a): Identify and fill gaps in ambient monitoring for wet and dry nitrogen deposition with emphasis first on adequate wet deposition coverage, second on ambient concentration coverage (inorganic species), third on dry deposition inferential modeling coverage, and fourth, for dry deposition micrometeorological measurements.

Research Needs:

1. Assess the applicability and limitations of available data from National Atmospheric Deposition Program/National Trends Network, NADP/NTN, Atmospheric Integrated Research Monitoring Network, AIRMON (wet and dry), Clean Air Status and Trends Network, CASTNet, Interagency Monitoring of Protected

Visual Environments, IMPROVE and other networks (to be identified) which operate with standard methods and protocols in order to assess the contribution of atmospheric deposition in the northern Gulf of Mexico. The assessment should address data gaps specific to the Gulf of Mexico in relation to developing improved estimates of nutrient deposition for all three areas of concern: the Gulf hypoxic zone and MARB, harmful algal blooms, and eutrophic effects in individual estuaries.

2. Evaluate the feasibility of expanding wet deposition measurements to include organic nitrogen or an appropriate surrogate. (This will be dependent on advances in basic research on organic nitrogen in the gas phase, in rainfall and in aerosols, and defining the methods and specific protocols for environmental measurements.)
3. Gather basic monitoring data focused on coastal land areas of the Gulf for wet deposition of nutrients using NADP/NTN protocols. Support addition of NADP sites to the Gulf coastal area, including National Estuary Programs, and supplemented by additional sites on coastal islands and piers where possible. The addition of several sites around the U.S. border of the Gulf will provide geographic data that is currently missing from the national NADP/NTN data sets. Some Gulf coastal sites can remain long-term members of NADP/NTN, while short-term sites should operate for at least 2 or 3 years. Evaluate the need for and location of additional monitoring sites in relation to local as well as regional concerns for eutrophic effects. Assess the utility of a hierarchy of site selections to ensure that the largest sets of observations are associated with the most regionally representative sites.
4. Increase dry deposition measurements in the Mississippi Basin to supplement NADP/NTN and CASTNet programs. A few additional dry deposition sites, particularly in the western area of the Mississippi Basin, with some spread to north and south, will address (at least partially) the uncertainty in the ratio of wet to dry deposition, and provide field checks on national-scale models of atmospheric deposition. CASTNet-like sites with a nutrient-only analysis list may be sufficient and offer cost savings. (See the basic suite of measurements in (6) just below, in this Milestone.) Site selection and network operation activities should incorporate research insights gained from co-located inter-comparisons of dry deposition rates, as calculated by existing inferential methods used in the monitoring networks and by state-of-the-art micrometeorological techniques.
5. Develop monitoring in open waters of the northern Gulf for wet deposition of nutrients using NADP/NTN protocols: install a small number of sites on platforms or buoys, and if possible, coordinate site locations to enhance ongoing Gulf water circulation and weather modeling to provide basic data that is currently completely absent. (Note that monitoring at buoys or other isolated sites must be designed to minimize interference from birds, and possible impacts on the data must be evaluated. Studies in marshes have shown this to be a serious concern.) If the GMP can assertively pursue and obtain support for such sites, via cooperation with Federal, State, or commercial entities, then such sites should be considered for use also as "super-sites".
6. It is critical that some dry deposition monitoring sites be established in the coastal zone, once research methodologies are refined to adequately account for perturbations to dry deposition induced by sea salt aerosols. Or, where dry deposition measurement sites are not feasible (due to site limitations or funding inadequacies), high-quality measurements should be undertaken for ambient air concentrations of inorganic gases and aerosols. (A basic suite of inorganic measurements should include: nitric acid, particulate nitrate, ammonia, particulate ammonium, sulfate, sodium, and chloride.) Such ambient

concentration data can provide valuable information for verification of atmospheric deposition models.

7. Obtain ambient concentration measurements of inorganic species over Gulf of Mexico waters, for the suite of gases and particles in (6), above. Such data can be combined with suitable meteorological data to develop standard estimation methods to assess dry deposition rates to the Gulf waters.

   Milestone (b): Collect atmospheric chemistry and meteorological data of sufficient quality, frequency and detail to validate, on a local scale, the dry nitrogen deposition inferential model, to support meta-analysis of regional atmospheric deposition trends, and to calibrate a synoptic scale transport model to achieve the desired tolerances in the tested hypotheses.

Research Needs:

1. Improve methods of estimating dry deposition of nutrient gases and aerosols directly to water surfaces in estuaries and near-coastal, northern Gulf waters. Establishing deposition velocities over open-water areas is a basic research need, and should address daytime and nighttime conditions in relation to Gulf parameters of temperature, humidity, warm waters, etc. Updated techniques or model factors will help fill a fundamental gap in knowledge and in methodologies to calculate dry deposition of nutrients on all US coasts. The research may focus on basic atmospheric processes, but should be translated into updated methods - whether for sampling ambient gases and aerosols or modifications in measuring micrometeorology at the deposition sites.
2. Review the availability of weather data (wind speed and direction, air and water temperatures, rainfall, etc.). Ensure that there are adequate data reporting stations to satisfy the level of modeling precision desired for coastal processes such as land/sea breezes and sea salt influences.
3. Assess the adequacy of sampling rate and frequency of wet and dry deposition observations. For example, many current monitoring networks operate on a weekly basis, while, for dry deposition events, a frequency of greater that diurnal may be necessary to prevent biases arising from covariance of pollutant concentrations and deposition velocities, or to capture land/sea breeze effects.
4. Characterize organic nitrogen, both in ambient concentrations, and in wet and dry deposition over terrestrial and coastal environments and over the northern Gulf near-shore open water. Fundamental studies on the definitions, methods and time scales of monitoring, and methods of chemical analysis for organic nitrogen are needed before general field monitoring can begin. Developing estimates for organic nitrogen in deposition will be important in the following areas. Studies over land areas will be important in modeling multi-compartment nitrogen fluxes in the Mississippi River Basin. Studies over coastal-land and near-shore water areas will be important in modeling the influences of organic nitrogen on algal blooms and consequent water clarity and oxygen demand in estuaries. Some existing studies indicate that organic nitrogen may be as much as 25% of total nitrogen deposition to near shore waters, so it should be considered in direct deposition of nutrients to the hypoxic zone and up-current areas.
5. Develop improved parameterizations of ammonia dry deposition to various landscape and vegetation surfaces relative to North American conditions (recent research has been done in Europe). Also research the existence of a compensation point (point at which the ammonia flux reverses direction) for vegetation typical of Gulf coast ecosystems.

   Milestone (c): Improve atmospheric nitrogen deposition estimates from conventional monitoring techniques by at developing selected network sites (super-sites) at which would be deployed: co-located, state-of-the-art monitoring equipment and techniques to address measurement uncertainties or suspected weaknesses.

Research Needs:

1. Establish modeling protocols and methodologies to extrapolate landscape-specific point measurements of dry deposition rates to regionally representative estimates. That is, dry deposition velocities are determined for the specific surface/land-use at each study site, so correctly combining numerous measurements and extrapolating to larger geographic scales will require improvements in techniques.
2. Further develop the multi-layer and similar inferential models to include size-segregated particle deposition and size-dependent sea salt influences.
3. Coordinate studies on atmospherically deposited nitrogen species with studies on the formation of "red tides" or similar blooms of harmful algae or bacteria. Provide data on nitrogen species and deposition rates to marine biologists involved in coastal ecological research whether in large-scale field studies or in mesocosm experiments, etc.
4. Assess the importance of nitrogen evasion (movements of all nitrogen compounds from the water into the air) as a component of the overall nutrient mass balance in northern Gulf waters. (This information will be important for Research Need (4) in Milestone (d), below.)

Milestone (d): Couple atmospheric with hydrogeological modeling in the Mississippi River Basin to simulate the biological, chemical and physical processing of nitrogen including the directional, biologically active (fixed) nitrogen flux at the land/water, land/air, and air/water interfaces. The goal of this modeling effort would be to develop a synoptic-scale spatially allocated relationship between a non-point source load on the watershed and a delivered load to the receiving waters. Similarly, couple Gulf hydrologic models with atmospheric exchange information, and with coastal and estuarine circulations.

Research Needs:

1. Coordinate research aspects of atmospheric deposition with the Monitoring and the Modeling Subcommittees within EPA's Gulf of Mexico Program.
2. Assess the performance of meteorological models that serve as the basis for estimates of the distribution of both wet and dry deposition over the Gulf.
3. Support studies aimed at reducing air quality model uncertainties. Modeling is the principal tool for assessment and policy development and consequently it is important to understand the limitations and minimize the uncertainties associated with the models.
4. Extend Gulf circulation models to include not only mass exchange with the atmosphere but also with estuary waters and subsurface offshore discharges. Assess the mechanisms for translating deposition to both the water surface and associated watersheds to an actual load in the Gulf estuaries and associated coastal ocean. The transport or exchanges of nutrients or harmful algal bloom organisms may be significant, and the waterborne influences among a series of adjacent estuaries, or between the estuaries and the Gulf hypoxic zone need to be assessed in relation to the relative importance of atmospheric deposition.
5. Assess the importance of model domain boundaries. Air sources outside of the continental U.S. may be contributing to the air component of the nutrient load reaching the northern Gulf. Portions of Mexico and Central American counties may be contained in the "airshed" for the northern Gulf, but may not be explicitly included in model domains

developed for assessments within the U.S.

6. Link Gulf water circulation and water quality models at various geographic scales with atmospheric circulation models, relating climatic data to the movements of Gulf waters and to the biologic cycles. How far "up-current" in Gulf waters, for example, will atmospheric deposition of nutrients have an influence on the hypoxic zone, in addition to direct deposition to the waters in the hypoxic-zone area. Over what time and spatial scales will deposited nutrients have influence on red tides and related phenomena?
7. After achieving progress in items (5) and (6) just above, consider whether models or other synoptic evaluations of the entire Gulf of Mexico and its watersheds are needed to understand water quality conditions in the northern Gulf and specifically in the hypoxic zone.

Goal 2. Assess the role that increases in human and domestic animal population densities in the Mississippi River Basin and in States that border the Gulf of Mexico may have on the direct and indirect atmospheric nitrogen deposition to the Gulf of Mexico and estuaries along the Gulf.

Milestone (a): Quantify the range of effect of nutrient deposition which arises from regions of urban and industrial development, and intensive agriculture. These regions can contribute more than average nutrient deposition to a significant geographical area downwind. Current deposition monitoring sites are generally located to sample "average" conditions, and relying only on such average data can result in significant underestimation of total deposition.

Research Needs:

1. Investigate the availability of emissions inventories. Many of these are developed in association with air quality modeling for compliance with the National Ambient Air Quality Standards. However, not all of the potential airborne nutrients are managed in these efforts, particularly ammonia.
2. Improve the emission inventory for ammonia. Quantify the annual net flux of atmospheric ammonia from various ammonia emission sources (for example, crops, synthetic fertilizers, automobiles, and livestock facilities).
3. Examine the "urban plume influence" on total nutrient deposition, especially direct deposition to northern Gulf Waters through intensive, event-based wet deposition studies coupled with dry deposition measurements and mobile platform (aircraft and ships) chemical/meteorological measurements. Assess the results and methods of this approach as recently utilized in Lake Michigan and Chesapeake Bay. Without such information, the typical approach to monitor deposition away from urban or industrial regions can result in underestimating total deposition. (A year-around site in the northern Gulf waters is not required, provided ship and/or aircraft-based studies can be arranged at more than one season for a few years.)
4. Study the ambient concentrations and the wet and dry deposition of ammonia plumes from large livestock facilities. This activity will assist in designing monitoring networks to accurately assess the nitrogen deposition from these sources which are among the major sources in the MARB. (Evaluate these sources in comparison to agricultural lands receiving intensive fertilizer applications – see Research Need (2) just above in this Milestone.)
5. Conduct regional modeling of nitrogen compounds transport, dispersion, transformation and deposition to determine the relative importance of local emissions versus regional scale transport of nitrogen to coastal watersheds and estuaries. Construct airsheds for selected watersheds, based on models.
6. Model the changes in atmospheric nitrogen deposition with changes in land use practices to assess the importance of atmospheric deposition as part of the "non-point load" which actually reaches rivers. Such studies would probably be geographically specific to several

geologic/climatic regions within the overall Mississippi River Basin.

7. Analyze trends in atmospheric deposition at regional and synoptic scales to evaluate the efficacy of nitrogen reduction strategies being installed under the national Clean Air Act or other legislative initiatives.

Goal 3. Assess the significance of the land-sea-air interface in estimating total deposition amounts. Two coastal phenomena, land/sea breezes and sea salt effects on aerosols, will influence deposition rates, especially dry deposition, sufficiently that simple extrapolation of measurements made inland to the coastal zone and near-shore waters would result in significant errors in estimating total deposition to estuaries, near-coastal watersheds and near-shore Gulf waters.

Milestone (a): Quantify the interactions of reactive nitrogen species with sea salt and the recirculation effect of the land/sea breeze and the warm Gulf waters that together promote higher nitrogen deposition rates along the coastlines of the northern Gulf of Mexico.

Research Needs:

1. Quantify the influence of sea salt aerosols on dry deposition estimates through co-located measurements of particle size distribution/chemical composition and trace gas concentrations of oxidized nitrogen compounds. The third generation gas and aerosol partitioning models (Aerosol Inorganics Model, for example) can predict not only the species phase but particle size mode, but should be validated with data obtained from the U.S. Gulf coastal lands and near-shore open water environments. Some current work is being pursued in connection with the Chesapeake Bay program and at Tampa Bay Estuary Program, but this work needs to be coordinated with additional studies, and evaluated for possible use throughout Gulf coastal areas.
2. Investigate with field studies the role of land and sea breezes on nutrient wet and dry deposition along the U.S. Gulf Coast and over near-shore waters. This will probably require samples being taken at least twice per day. A full year of sampling may not be necessary, but seasonal effects should be studied. Nutrient transport and deposition on land and sea breezes is a fundamental gap in knowledge and in methodologies on all US coasts. Investigations of land/sea breeze dynamics should be coupled with studies of urban plume impacts to account for urban plume transport, chemical transformation, and recirculation phenomena, and should incorporate coupled chemical and micrometeorological measurements, including the deployment of vertical wind profilers, and where possible, coordinated aircraft-based chemical measurements.

Goal 4. Quantify the atmospheric nitrogen deposition, in terms of oxidized nitrogen, reduced nitrogen and dissolved organic nitrogen, to the Mississippi- Atachafalaya River Basin (MARB), U.S. estuaries along the Gulf of Mexico and their watersheds, and the waters of the northern Gulf of Mexico.

Research Needs:

1. Gather, index, and periodically analyze public documents which address research, monitoring, or modeling of atmospheric deposition in the Gulf of Mexico region and the MARB. Actively contact all U.S. Gulf National Estuary Programs, and NOAA, EPA laboratories, Marine Fisheries Service studies, and Federal and State parks and wildlife reserves in the Gulf region, and also canvas universities and independent laboratories (e.g. Mote Marine Lab in Florida) in the Gulf states to obtain documents and reports of studies.
2. Actively collect copies of data sets of past and ongoing studies of atmospheric deposition which were/are performed in the Gulf region and Mississippi River Basin with EPA or NOAA support or coordination. Assist transfer of these to

EPA's central program to archive and maintain data sets of environmental measurements.

3. Conduct studies on atmospheric deposition to the U.S. Gulf Coast estuaries and their watersheds, evaluate recent studies on atmospheric deposition and refine the atmospheric deposition components in the MARB nitrogen loading calculations by Goolsby, et al. (1999).
4. Seek support for developing or applying synoptic-scale analysis methods including modeling and meta-analyses to combined data sets from several local or regional programs.
5. Coordinate with international activities in research on nutrient loading (from all pathways), especially with countries around the entire Gulf of Mexico.

Goal 5. The findings from research and monitoring should be summarized and interpreted concerning the sources, impacts and relative importance of atmospheric deposition to coastal water quality, and active programs supported to distribute and share the information with resource managers and with the general public, as well as with researchers.

Research Needs:

1. Collate, analyze and interpret data and other information on the sources, impacts and relative importance of the atmospheric deposition to coastal water quality, as collected by this program and others in the northern Gulf region, for distribution to resource managers and to researchers.
2. Establish and maintain regular and active coordination with EPA's Chesapeake Bay Program and Great Lakes National Program concerning atmospheric deposition studies, findings, and plans. Coordinate with atmospheric deposition studies and monitoring in the U.S. Gulf Coast region being carried out under US National Park Service and National Wildlife Refuge support, as well as other Federal and State programs. Where possible, obtain detailed knowledge of the data sets as well as of reports or summary information.

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14. Habitat Focus Area - Emergent Coastal Wetlands Research Topic

Description of the Problem: The importance of coastal emergent wetlands in terms of productivity, faunal habitat, and protection from storms is well known. Loss and degradation of coastal emergent wetlands are occurring at an alarming rate. In the Gulf of Mexico (Gulf), there are 1,317,900 ha of coastal emergent wetlands (Johnston et al. 1995). Loss rates vary from state to state and are highest in Louisiana where rates have been reported as 65 B 93 km^2 yr^{-1} (Barras et al. 1994, Day et al. 1999). The loss in Louisiana alone translates into 80% total national loss of coastal wetlands (Boesch et al. 1994). Losses result from both natural and anthropogenic sources. Some known or suspected causes of loss are sea level rise, dredge and fill, salt water intrusion with effects compounded by canal construction, subsidence, a lack of sediments and/or nutrients depending on location. For some areas, including coastal Louisiana where there is both the most wetlands and the highest loss rates, high loss rates are projected to continue for decades. Not only does this result in loss of marsh area per se, but also results in loss of habitat for myriad animals, critical reductions in primary productivity and thus detrital input to estuaries and near shore marine areas, a loss in protection from storm surge, and numerous other known wetland functions.

As a result, the health and sustainability of our coastal emergent marshes and mangrove forests, and the estuaries coupled to them in the Gulf region are at significant risk. Consequently, there has been an increasing emphasis on habitat restoration in all regions of the Gulf coastal zone, including the most recent attempts to address the mammoth problems in Louisiana through the Coastal Wetlands Planning, Protection, and Restoration Act (CWPPRA) and Coast 2050 activities. The CWPPRA projects authorized over the first eight years are anticipated to create, restore, or protect 28,329 ha of marsh during their 20-year life spans. When combined with other restoration projects developed under the Water Resources Development Act, only 23% of the projected 50-year marsh loss may be prevented. If the current land loss rates continue unabated, by the year 2050 coastal Louisiana is estimated to lose an additional 263,000 ha of marsh and swamp even with current restoration efforts (Louisiana Coastal Wetlands Conservation and Restoration Task Force, LCWCRTF and Wetlands Conservation and Wetlands Conservation and Restoration Authority, WCRA 1998).

Overview and Importance: However, there is not a sufficient scientific understanding of the nature and function of emergent coastal wetlands to allow unequivocal and accurate decisions by scientists and managers in many restoration or other management cases. This point is clearly demonstrated by the unexpected recent dieback of huge expanses of salt marsh in Louisiana. During the summer of 2000, some 17,000 ac of marsh died with only stubble or mud flat left and an additional 100,000 ac appeared to be dying or severely stressed (La Coast fact sheet). Most of this was centered in the Barataria-Terrebonne estuary system but dead or stressed marsh was reported in western parts of the state and even in Texas south of Galveston Island. While the event is likely associated with the recent extreme drought conditions, studies over the summer have not been able to pinpoint the cause(s). Further studies are planned and discussions of the possible need for large scale restoration projects are underway.

Research is required to quantify the extent and nature of these critical wetland ecosystems, the abiotic and biotic factors influencing their structure and function, and the effects of disturbance and invasive species. In order to sustain these systems, research is also needed in the fields of emergent marsh restoration and assessment. The research needs listed below should be regarded as applying to coastal marshes of various types (such as salt, brackish, fresh, and flotant) and mangrove ecosystems.

Major Gulf Coastal Emergent Wetlands Research Areas: The research needs listed below best address the objectives and sub-objectives, and will provide a more complete understanding of the ecosystems and thus allow more rapid and complete evaluation of unanticipated problems that arise in the future.

Research Goals. In order to address the Gulf management objectives articulated above, we have developed six broad goals and list critical research topics that address gaps in knowledge for the goals. Each of these goals, and the research topic areas under them, are intended to assist in attaining the following overall goal: To develop a research program that enhances the links of science to natural resources management and land-use planning for Gulf emergent wetlands.

<u>Research Goal 1</u>. Understand the status, structure, and function of coastal wetland systems and develop tools to evaluate these systems over large spatial and temporal scales.

1. Conduct landscape scale investigations on the relationships among adjacent wetland systems linked hydrologically and by common faunal use. This will likely necessitate further development of remote sensing and GIS tools into the study of emergent wetlands.
2. Develop and apply more fully aerial photography, remote sensing, and GIS tools for the assessment of long-term change in the emergent wetland landscapes throughout the Gulf.
3. Conduct long-term observational and experimental field studies on emergent wetland population and community dynamics. Such studies are required to enhance our understanding of how these systems function and change over time; as well as for documenting the ecological factors underlying long-term changes.

<u>Research Goal 2</u>. Understand the habitat linkages of coastal wetland and attendant estuarine systems.

1. Initiate studies designed to quantify the linkages among emergent wetlands, submerged systems, and fisheries. This will include more complete work on

detrital production, decomposition, export, and trophic linkages, as well as, direct use of habitats by juveniles of fishery species.
2. Initiate Gulf-wide investigations (i.e., across state and national boarders) into the use of emergent wetlands by migratory species (e.g., birds, natant fauna). Baseline data from such studies are needed to measure trends in the habitat function of emergent wetlands.
3. Improve our understanding of the distribution and habitat requirements of early-life stages of fishery species that utilize emergent wetlands.

Research Goal 3. Understand the influences of and interactions among biogeochemical factors and environmental stressors on emergent wetland systems and habitat utilization; including short-and-long-term temporal cycles and fluxes and inter- and intra-year differences in wetland diversity, productivity, and stability.

1. Analyze fully the separate and combined effects of various biogeochemical factors (e.g., salinity, sulfide, nutrients, etc.) and soil features on different wetland species and on species-species interactions. This will also be required for an understanding of long-term wetland change.
2. Determine the effects of elevated carbon dioxide on the different emergent coastal wetland ecosystem structure, productivity, succession, and rates of carbon sequestration.
3. Evaluate the effects of pollutants such as oil and mercury on emergent wetlands where such pollutants occur.
4. Further quantify the ability of emergent wetlands to absorb and naturally-detoxify various contaminants.

Research Goal 4. Assess effects of and develop predictive models of disturbance (human and natural) on the productivity and longevity of coastal wetland systems.

1. Conduct studies of plant-herbivore/parasite/disease disturbance relationships and document their effects on productivity, reproduction/colonization, emergent wetland loss, and habitat value of various emergent wetland types.
2. Initiate Gulf-wide assessments of eustatic sea level rise, subsidence, etc. and their individual and combined effects on wetland loss rates. Enhance modeling techniques to permit better predictions of future trends and to identify and rank geographic areas where restoration may be needed
3. Analyze the causes and ecological consequences (to productivity, genetic diversity, erosion, habitat value, etc.) of the die-off in Spartina alterniflora and possibly other emergent wetland species recorded in recent years in various portions of the Gulf.
4. Document the effects of invasive plant species (such as Phragmites and Tamarix) and animal species (such as nutria) on emergent coastal wetlands; and develop predictive models of the spread of invasive species and their likely long-term ecological and economic consequences in the Gulf region.
5. Initiate a program for assessing the potential for introduced species to become invasive and to have adverse ecological effects.

Research Goal 5: Develop research programs to evaluate the success of coastal emergent wetland restoration approaches, especially emphasizing the importance of reconstructing ecological functions; and, evaluate innovative means for conducting successful restoration.

1. Perform long-term studies on the success of emergent wetland restoration. Evaluations of plant survival, productivity, genetic diversity, species succession, habitat use, fisheries value, functional equivalencies, soil development, etc. are needed to justify continued large monetary expenditures on wetland restoration/creation.
2. Initiate further research on innovative and/or low-cost techniques of emergent wetland restoration and assessments of optimal configuration.
3. Assess the effects of large scale freshwater diversions on emergent

wetlands and adjacent subtidal systems and fishery species.
4. Determine the potential for Gulf-wide, standardized, rapid assessment protocols of wetland function, loss, and restoration success.

Research Goal 6: Evaluate the utility of various indicators of ecosystem vitality or change. Determine the utility of such indicators in decision support systems.
1. Development of Gulf-wide databases and models for use in developing natural resource decision making systems.
2. Conduct research aimed at developing indicators of emergent wetland condition (extent and health).

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15. Habitat Focus Area - Seagrasses Research Topic

Problem Statement: Seagrass habitat loss ranges from 20% to 100% over the last 50 years for most estuaries in the northern Gulf of Mexico (Gulf). (Handley) Most of the seagrass acreage loss can be attributed to widespread deterioration of water quality, including light attenuation, increased water motion and human disturbances.

Overview and Importance: The coastal zone of the Gulf is endowed with immensely productive habitats whose ecological functions enhance all of the Gulf's wildlife and fishery resources. Seagrass communities are among the richest and most productive ecosystems in the world. They protect and improve water quality, provide shoreline stabilization, and are important habitats for nursery and cover for an array of fish, birds, shellfish and other wildlife. Collectively, seagrasses provide shelter and sustenance for a variety of fishes, and invertebrates, including the young of many commercially and recreationally important stocks. In addition, seagrasses are the sole food of one waterfowl species (the redhead, Aythya americana) and important foraging habitat for several other waterfowl species, sea turtles and manatees. The diversity and amount of biomass produced in or dependent upon seagrass beds are enormous. Submergent seagrasses occupy over 323,760 hectares (800,000 acres) within the estuaries and shallow near-coastal waters of the Gulf (Iverson and Bittaker, 1986). Approximately 95 percent of this acreage is in Florida and Texas where seagrasses occupy about 20 percent of the bay bottoms (Thayer and Ustach, 1981). Although often considered continuous around the Gulf's entire periphery, a combination of low salinity, high turbidity and wave energy, and human disturbances results in only scattered patches of seagrass, mostly in bays from the Florida panhandle to Laguna Madre, Texas.

The distribution of seagrass beds is limited by light attenuation, high wave energy and human disturbances. Two primary factors affecting light attenuation are depth and turbidity. Increased depth, resulting from subsidence, limits the occurrence and density of seagrass beds. Activities which increase water turbidity, such as dredging, and alterations in coastal watersheds that lead to increased runoff have caused losses in seagrasses. Decreases in light reaching seagrasses because of the stimulation of growth of phytoplankton, epiphytes and macroalgae resulting from nutrient enrichment have causes even more widespread losses of seagrasses. Lewis, et al. (1985) noted that Tampa Bay had lost about 80 percent of its original seagrass beds by 1982. The sea grass beds which remain in Tampa Bay, and other bays and nearshore areas, are stressed and impacted by human activities (Zieman and Zieman, 1989). For example, propeller scars, prominent in many sea grass meadows, may take years to heal by revegetation. In Laguna Madre, seagrasses have undergone large changes in species composition as well as losses in area because of human impacts. Decreases in seagrass acreage can also be attributed to disease. (Mass Mortality of the tropical seagrass Thalassia testudinum in Florida Bay (USA) Mar Ecology Program Ser 71:297-299.) M.B. Roblee, T.R. Barber, P.R. Carlson, Jr., M.J. Durako, J.W. Fourqurean, L.K. Muehlstein, D.Porter, L.A. Yarbro, and J.C.D. Zeeman. 1991.

Major Gulf Research Objectives and Actions:

1. Assess the ecological status in terms of areal and temporal extent and quality of seagrasses and determine the trend in extent and quality.
   a. Quantify and map current seagrass acreage in Gulf Coastal Waters.
   b. Identify indicators that best describe "quality" of seagrass beds and are appropriate for small- (a seagrass bed, an estuary) and large-scale (biogeographical region, state, Gulf) monitoring and assessment activities.
      - What is the range of expected values for seagrass indicators?
      - What is the natural variability of these indicators?
      - What spatial and temporal scales are needed to accurately establish values for these indicators?
   c. Describe the rapid assessment techniques and sample designs that can be used to routinely monitor seagrass beds at various spatial scales.
2. Identify the factors which determine establishment and persistence of seagrasses.
   a. Identify water quality and other guidelines (e.g., nutrients, light, chlorophyll a) that will protect and preserve Gulf seagrasses.
      - Quantify and map the geological and historical seagrass acreage to determine quantity and locations of declines.
      - Conduct field and laboratory studies to document cause-effects relationships and describe stress thresholds for effects.
      - Quantify the sources of human-induced declines of seagrass habitats in the Gulf and correlate with seagrass bed condition to develop hypotheses regarding cause.
      - Document "significant" destruction caused by biological stressors; identify biotic agents; and define anthropogenic interactions, if any.
   b. Determine if interactions among stressors limit persistence (or growth) of seagrasses in areas that meet minimum light requirements.
   c. Define the water column and sediment characteristics required for establishment of seagrasses in areas to be restored.
   d. Document and monitor restoration success rates of existing and new seagrass planting technologies.
3. Determine the critical factors which determine natural structural and functional characteristics of seagrass habitats.
   a. Determine the relationships among primary and secondary productivity and landscape features (e.g., patch vs continuous habitat, large vs small habitats), location within an estuary, and association with adjacent habitats.
   b. Determine if and how habitat function (e.g., fish and shellfish utilization) differs among different species and densities of Submerged Aquatic Vegetation, SAV, including seagrasses, macro algae, and other aquatic plants.

Major Deliverables:

Report on Status and Trends of Seagrasses in the Gulf 2004
Protocols for Mapping and Monitoring Seagrasses 2002

Water Quality Guidelines (Nutrient, Light, Chlorophyll) to Protect and Preserve Seagrass Beds
Water Quality and Sediment Characteristics Required for Successful Establishment of Seagrasses

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16. Public Health Focus Area - Biotic Pathogens Research Topic

Description of the Problem: Coastal and shoreline development, inefficient waste water treatment facilities, animal feedlot operations, and urban runoff and improper disposal of human waste from boats all contribute to fecal contamination of our Nation's waters. Humans who swim and recreate in water contaminated with fecal pollution are at an increased risk of contracting gastrointestinal disease; respiratory, ear, eye, and skin infections; meningitis; and hepatitis. Humans who consumer fish and shellfish from these waters are also susceptible to a wide range of organisms with variety of outcomes including mild to severe gastroenteritis, septicemia and in extreme cases, death.

Overview and Importance: The objective of this document is to present areas in which research is needed to assist in either identifying the causative organism in disease outbreaks or decreasing the incidence of disease related to exposure to biotic pathogens. The document is broken down by topic area and provides a brief explanation as to the importance of each area.

1. Pathogen Indicators

Indicator organism(s) are a fundamental monitoring tool used to measure both changes environmental (water) quality or conditions and the presence/absence of hard to detect in target (pathogenic) organisms. An indicator organism acts as a representation of the presence/absence of a pathogenic organism surviving under similar physical, chemical and nutrient conditions. For fecal contamination, indicator organisms must: 1) be consistently and exclusively associated with the intestinal sources of the pathogenic organism, 2) occur in greater numbers than the pathogen, 3) be more resistant to environmental stresses and persist for a greater length of time than the pathogen, 4) not proliferate to any great extent in the environment, and 5) yield a simple reliable and inexpensive method for detection, enumeration, and identification of the indicator organism. Indicator bacteria are usually harmless, more plentiful and easier to detect than pathogens.

EPA and FDA currently have conflicting standards for similar bodies of water. EPA published Ambient Water Quality Criteria for Bacteria - 1986, which recommended the use of E. coli and enterococci to replace fecal coliforms as the recreational water quality indicator organisms. Fecal coliform bacteria are used as an indicator to monitor shellfish harvesting waters through the National Shellfish Sanitation Program (NSSP). Also, there is a concern that the risk associated with pathogen indicators from nonhuman sources may not be the same as that from human sources. Given these points, there are several research questions that need to be answered. These include:

a. Are the current indicator recommendations adequate or are new indicators better at predicting disease outcomes in human beings? Research in this area should be focused at the epidemiological association between the indicator and disease outcomes.

b. Is there a single indicator which could be used for both recreational and shellfish purposes that would adequately protect the public? Research should be focused on providing sufficient evidence that a single indicator organism could adequately protect the public from disease due to recreational contact and shellfish consumption.

c. Is there a method available to rapidly detect the indicator of interest? Water quality and shellfish agencies must be able to detect the indicator quickly to adequately protect the public. Methods which can accurately enumerate the indicator in less than 24 hours should be the goal of any research into this arena.

d. Is there a difference in the risk of disease related to exposure from human vs. nonhuman sources of indicator organisms? Current data in this area is inconclusive. Research in this area should attempt to determine if there is a difference in the disease outcomes due to various sources of these organisms and routes of exposure.

2. Pathogenic Organisms

While the indicator organisms identified above serve as a good tool for identifying the presence of pathogenic organisms, some organisms either a) do not associate with the indicator or b) are accumulated over time in finfish/shellfish tissues. Therefore, it would be of interest to have methods available for these types of organisms to provide an additional level of protection for the public.

a. What organisms may be present at levels that would cause disease endpoint in humans when indicator levels are acceptable? The Gulf of Mexico Program Public Health Focus Team has already identified Norwalk virus as one of the agents of concern. Research in this area should focus not only on the organisms themselves but also on the dose of the organism that would be necessary to evoke a disease response.

b. Is there a method available to rapidly detect the organism of interest? Cultivation and detection of some organisms can be quite difficult given the requirements of the organism and/or the matrix from which the organism is being extracted i.e. shellfish tissue. Research in this area should be focused toward rapid and accurate detection of the causative organisms identified above.

3. Pathogen Source Tracking

Identification of fecal bacteria sources is necessary for accurate interpretation of the indicators. Non-point source runoff from forests, pasturelands, and urban areas can carry the fecal material of domestic and feral animals into recreational waters. Animal and waterfowl have been recorded as the cause of a beach advisories and closings. As regulatory agencies move towards conducting Total Maximum Daily Loads (TMDLs) for many of these waterbodies, it would be of interest to identify the true source of the bacteria so that adequate reduction strategies can be targeted to an area.

a. What are the best methodologies to use to conduct source tracing? Currently, source tracing methodologies include ribotyping and restriction patterning. Research should focus on which methodologies produce consistent and specific results.

b. Of the methodologies identified above, what is the minimum dataset necessary to construct a valid library of sources? All methodologies require that representative animals in the watershed be sampled to assemble a library of bacterial types associated with each animal. Research should be focused on the actual number of animals of a given species that need to be sampled to give a valid representation of the microbial flora associated with that species.

c. To what geographic extent can a bacterial library be applied? Once a library is constructed, it would be of interest to know where such a library can be applied so that reconstruction would not be necessary. Research should focus on the variability of microbial flora in animal species within a watershed, in adjoining watersheds, and elsewhere to resolve this question.

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17. Public Health Focus Area - Toxic Substances Research Topic

Problem Statement: Amount of toxic substances and chemical compounds entering the environment in the recent years decreased significantly due to the great effort of established federal, state and local programs. However, as reported reductions of chemical releases continue, the presence of new and more persistent toxic substances rises a concern today. The Toxic Release Inventory data lists more then 600 chemicals and chemical categories, many of them are carcinogens, reproductive or developmental toxicants.

The coastal region of the Gulf of Mexico has experienced rapid economic and, as a result, development growth. The industrial, municipal, and agricultural activities associated with this development contribute toxic substances to Gulf waters from operations, permitted discharges, stormwater runoff, and accidental releases. According to Toxic Release Inventory data (TRI 1998-1999) all five Gulf of Mexico states are listed in the top 25 states nationally for total chemical emissions to the environment. The Gulf of Mexico region has more permitted point sources of pollution than any other region in the US (USDOC 1990), and some of the industrial and municipal facilities discharge wastes directly into the waters of the Gulf or the surrounding estuaries (Weber et al. 1992). This direct exposure to hazardous wastes is a problem particularly in estuarine and other protected coastal areas where waste inputs are usually concentrated and where the dispersion and dilution, which occur rapidly in the open ocean, are delayed by restricted interchange with general oceanic circulation. As persistence and concentrations increase, certain elemental contaminants, synthetic organic compounds, nutrients, and other substances contained in wastes may reach levels, which can cause undesirable environmental effects.

There are two basic ways by which chemical contaminants can affect marine resources: 1) by directly affecting the exposed organism's health and survival, and 2) contaminating fisheries resources that other species, including humans, may consume.

Fish and shellfish consumption is generally the major route of human exposure to toxic chemicals from the Gulf system. The effects of many single toxic compounds are fairly well established, however, bioaccumulation rates vary significantly for different contaminants and for different organisms. It is difficult to establish the potential degree of human health hazard posed by their presence in seafood, the form in which they exist, and the impact of other coexisting chemical agents. The health effects of exposure to complex chemical mixtures and repeat intermittent exposures needs to be studied.

To provide credible and balanced guidance for protecting the valuable resources of the Gulf of Mexico, there is a need to carefully and clearly determine which of the biological effects in our coastal waterways are due to contaminants, and their relative importance. Such information, combined with the knowledge of the levels at which contaminants have toxic effects in biota, is crucial in providing rational guidelines for establishing sediment and water quality standards, and for setting criteria for natural resource damage assessment and subsequent restoration of degraded habitats. It is important that research and scientific assessment is integrated with policy and regulatory activities to design and implement a comprehensive strategy for managing and protecting the Gulf of Mexico resources.

Major Goal of the Gulf of Mexico Research Program: Identify appropriate approaches to reduce, control, and where possible, eliminate the adverse impacts to human health and the environment from toxic substances and pesticides in the Gulf of Mexico area.

Major Gulf of Mexico research objectives and actions:

The following addressed research objectives are identified with decreasing priority.

1. Evaluate existing databases and promote development of valid methods of data collection and analysis.
   a. Identify the contaminants of concern with the most significant potential for impact on human health and the

environment to assist state and local governments in making risk management decisions,
b. Incorporate background information into a toxic contaminants database to allow assessing the extent and severity of contamination; including quantifiable information about sources of contamination, surface water discharge, atmospheric deposition,
c. Verify valid methodology and procedures for sampling and analysis to ensure adequate precision, accuracy and consistency to allow comparisons across the Gulf, including proper QA/QC documentation to allow correct evaluation, (priority: medium)
d. Review and develop criteria to evaluate existing toxicity data with documentation of organism's size, age, sex, physiological stage of development and tissue type, and to prepare an inventory report. (priority: low)

2. Characterize factors, which support exposure identification and risk assessment.
a. Characterize chemical-specific risks to provide a guidance to state health agencies and Industry, and justify regulatory or site-specific decisions,
b. Improve existing models of prediction of environmental fate, duration and route(s) of exposure to chemical contaminants to ensure appropriate implementation of a risk assessment
c. Identify effects of repeated exposure of an individual organism/ target population to contaminant with respect to level of health hazard posed to a consumer from the consumption of Gulf seafood,
d. Establish baseline values for chemical residues and dose- responses to be able to identify problems promptly and to support assessment of ecosystem-level effects and public health risks caused by exposure to multiple toxic substances,
e. Include in an experimental design physical, chemical and biological factors to determine mean baseline values and to understand toxicity changes with the seasonal variability associated with those parameters.

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GMP Research Topics

18. Invasive Species Focus Area - Invasive Species Research Topic

Note: *In recognition of the extensive past efforts in assessing the scientific knowledge and uncertainties related to Invasive Species conducted by the Characterization Report Workgroup, as ad-hoc working subcommittee of the Gulf of Mexico Program Invasive Species Focus Team, and for consistency, the materials contained in this research needs document were abstracted from "An Initial Survey of Invasive Aquatic Species Issues in the Gulf of Mexico Region". Reference should be made to this and referenced predecessor documents for greater detail.*

Description of the Problem: The transformation of the natural environment and worldwide transport of people and cargo have facilitated the introduction of invasive species at a rate that overshadows natural rates of species movement (OTA 1993, Mack et al. 2000). It's been estimated that about 50,000 invasive plant, animal, and microbial species have been introduced into the U.S. (Pimentel et al. 1999) and, of these, over 6,500 have established populations (Williams & Meffe 1999). Only a subset of these established invasive species directly threaten the diversity or abundance of native species or the ecological sustainability of occupied ecosystems. It's been estimated that the overall economic loss due to invasive species is more than $138 billion per year (Pimentel et al. 1999).

A subtropical climate and abundant aquatic habitats make the Gulf region naturally hospitable to invasive aquatic species (Devine 1998, Cox 1999). The region is even more vulnerable to invasive aquatic species due to the magnitude and variety of introduction pathways created by, for example, i) large numbers of people, vessels, and airplanes, and large volumes of cargo, coming through multiple large-scale, international ports and airports, ii) year-round, cross-state recreational boating, fishing, and other aquatic recreational activities, iii) the Gulf Intracoastal Waterway and Mississippi River, which provide the 5 Gulf states with an aquatic connection to more than half of the 48 states in the continental U.S. and iv) substantial horticultural and aquarium trade industries import, breed, grow-out, and warehouse a large variety of invasive aquatic species. Once established in large aquatic ecosystems, eradication of aquatic invasive species is almost impossible (Howells 1999, Benson 2000).

Overview and Importance: Aquatic invasive species directly threaten native species and ecosystems and regional and national economic systems. Ecological impacts can include i) loss of or declines in native species due to competition for food and space, predation, habitat alterations, and the introduction of diseases and parasites, ii) changes in ecosystem structure and function, iii) rearrangement of tropic relations, or iv) genetic effects through hybridization and interbreeding (Mills et al. 1994, Williams and Meffe 1999, Benson, 2000).

Major Gulf Research Objectives and Actions:

In March 2000, the Research Subcommittee of the GMP Monitoring, Modeling, and Research Committee, assisted by the Invasive Species Focus Team Co-Chairs, defined the Priority Research Questions for the GMP's Invasive Species Focus Area. These Priority Research Questions were further refined by the ISFT, which served as the Expert Panel, in June 2000.

1. What methods, data, or models are required to assess the potential human health and/or ecological risks associated with invasive species introductions?
   a. What predictive associations/models are required to assess species and source locations that pose a high risk to Gulf waters?
   b. What laboratory and field methods, data, and models are required to assess both human health and ecological risks associated with introductions of invasive species?
2. What is the ecological and economic extent and effects of invasive species in the Gulf ?
   a. What invasive species are present in the Gulf and what are their economic, human health, and ecological effects?
   b. What methods, models, and data are required to detect and track subsequent invasions and spread of invasive species in Gulf watersheds and Gulf-wide?
3. What invasive species are transported to and released into Gulf ports from ship ballast?
   a. What methods are needed to monitor compliance of ballast exchange in the Gulf of Mexico?
   b. What are the characteristics of biological (taxa and quantity) contamination of ballast discharges into major Gulf ports?
   c. What is the anticipated 10-year shipping forecast for Gulf ports?
   d. What methods are needed to detect unknown species in ballast water released into the Gulf , or to monitor for worst case scenarios like human pathogens and/or plant pathogens?
   e. What are the ecological vulnerabilities, associated with invasive species, of particular Gulf areas subject to shipping pressures?
4. What are the ecological risks associated with the introduction of invasive viruses into Gulf waters from aquaculture and seafood processing? At the same time, what are the risks associated with viruses that enter aquaculture facilities from a variety of sources, including stocked shrimp, processing wastes carried into ponds by birds, etc.
   a. What simple biological/chemical indicators are required to determine the presence/absence of shrimp viruses in environmental samples?
   b. What biological indicators are required to routinely monitor for the presence of viruses in wild populations of commercially important species?
   c. What are the chemical and biological characteristics of effluent from aquaculture and seafood processing plants that might affect the Gulf, or other areas receiving aquaculture products?
5. What technologies might prevent and/or control invasive species introductions?
   a. What techniques are effective in the shipboard treatment of ballast water?
   b. What are the best management/treatment practices to identify and control the release of shrimp viruses and other microorganisms from aquaculture and seafood processing plants, or to other areas receiving aquaculture products?

Research Needs:

The following specific research needs were defined by the ISFT Co-Chairs, and refined by the ISFT in June 2000. They are organized by generic topic areas, and listed without regard to priority.

1. *Risk Analysis*
   a. Determine what methods, data, or models are required to assess the risk of trade pathways and trade partner sources associated with invasive species introductions.
2. *Prevention of New Introductions*
   a. Determine preventive strategies and develop model control mechanisms.
   b. Develop risk assessments for potential and initial presence of invasive aquatic species.
   c. Inventory Gulf marine waters for invasive species.
3. *Reducing the Spread of Established Populations*

a. Develop basin specific and Gulfwide quantitative databases to pinpoint and track invasions and spread of invasive aquatic species.

b. Conduct a Gulfwide status and trends analysis on invasive species (aquatic and terrestrial) to include, but not limited to, species, geographic distribution, habitat types(s) invaded, impacts, rate of spread, modes of spread, environmental requirements, etc.

c. Develop monitoring protocols that can be incorporated into existing water quality monitoring to identify presence of unknown species or changes in ecology that might be attributed to an introduction. Data would be made available for local follow-up or agency follow-up, as appropriate.

d. Inventory Gulf marine waters for invasive species.

4. *Ballast Water: Management and Treatment*

a. Determine levels of research activity on ballast water treatment

b. Determine what methods, data, or models are required to assess the risk of ballast water pathways and trade partner sources associated with invasive species introductions.

c. Develop mechanisms to ensure that open ocean exchanges have been performed (a USCG research project).

d. Develop mechanisms to regulate ballast water discharge. Refine methods/procedures for monitoring compliance of ballast exchange in the Gulf of Mexico.

e. Characterize biological contents (taxa, levels) of ballast discharges in major ports.

f. Establish a long-term database (10+ years) of shipping activities of Gulf Ports.

g. Determine the effectiveness of ballast water exchange (90 percent for commercial vessels and 2 times for military vessels) in achieving percent kill or removal of organisms in the ballast water column and sediments.

h. Determine the effectiveness of ballast water exchange (90 percent for commercial vessels and 2 times for military vessels) in preventing the establishment of reproducing, self-sustaining populations of invasive aquatic organisms. The research question here is what critical population densities are needed for a successful invasion (establishment).

i. Determine the effectiveness of alternate compliance technologies (ballast water treatments) in achieving percent kill or removal of ballast organisms and in the prevention of established populations of invasive aquatic species.

5. *Ballast Water: Ecosystem Effects*

a. Determine what methods, data, or models are required to assess the risk of ballast water pathways and trade partner sources associated with species introductions.

b. Determine the ecosystem vulnerability to invasive aquatic species of the major Gulf ports and adjacent inland waters. (This might be done by comparing environmental parameters of Gulf ports with those of the primary foreign ports of origin (ports where ballast is collected) for the majority of shipping at each Gulf port destination.)

c. Determine similar vulnerabilities for aquaculture and water garden imports, handling, marketing, etc. through the Gulf region.

6. *Shrimp Viruses*

a. Develop and test Best Management Practices (BMP) for identification and control of shrimp viruses during the delivery of seafood.

b. Develop simple probe(s) for determining the presence/absence of shrimp viruses.

c. Establish a monitoring program/protocol to test for the presence of virus in wild shrimp populations.

d. While the research needs represent a broad area of research, those related to shrimp viruses and ballast water, the first two primary topics related to the Gulf of Mexico Program's Invasive Species issue area, are of greatest importance.

Major Deliverables: (None specified)

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